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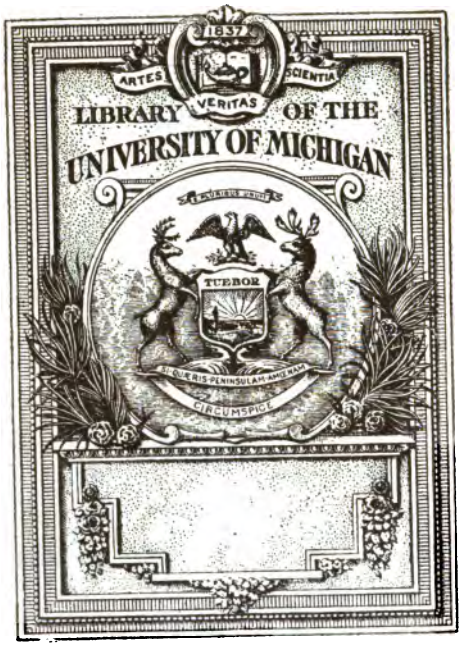


THE GIFT OF
PROF. ALEXANDER ZIWET

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Halley, Edmond

# *Miscellanea Curiosa.*

BEING A

# COLLECTION

Of some of the Principal

# *PHÆNOMENA*

IN

# NATURE,

Accounted for by the Greatest Philosophers of this Age.

TOGETHER

With several DISCOURSES read before the ROYAL SOCIETY, for the Advancement of Physical and Mathematical Knowledge.

*LONDON:*

Printed by *J. B.* for *Jeffery Wale*, at the *Angel* in St. *Paul's* Church-yard; and *John Senex*, in *Hemlock-Court*, near *Temple-Bar*, 1705.

UNIV. OF MICH.

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UNIV. OF MICH.

*His Excellency*
*Alexander Lord Polwarth, Eldest Son of Patrick*
*Earl of Marchmont, &c. His Majesties Ambassador*
*Extraordinary & Plenipotentiary to the Congress at*
*Cambray, Lord Clerk Register of Scotland, & Lord*
*Lieutenant of Berwickshire. Anno 1722.*

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Grad. 3
Prof. Alex. Ziwet
gt.
12-17-1923

# TO THE READER.

SOME of the Principal Discoveries and Enquiries, both in *Physical* and *Mathematical* Learning, being regiſter'd in the Voluminous Journals of the *Royal Society*, are amongſt a multitude of leſs uſeful Matters, ſo Obſcurely hid, that but very few inquiſitive Gentlemen ever ſo much as heard of them.

The Deſign therefore of the enſuing Collection, is to digeſt in a convenient Method, all the moſt curious *Philoſophical* and *Mathematical* Diſcoveries, as they are to be met with, which may any way tend to the Uſe of Life, or Advancement of Arts and Sciences.



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*The True Theory of the* Tides, *extracted from that admired Treatise of Mr.* Isaac Newton, *Intituled,* Philosophiæ Naturalis Principia Mathematica; *being a Discourse presented with that Book to the late King* James, *by Mr.* E. Halley. 13

*A Theory of the* Variation *of the* Magnetical Compass; *by Mr.* E. Halley. b27

*An Account of the Cause of the Change of the* Variation *of the* Magnetical Needle. *with an Hypothesis of the Structure of the* Internal Parts

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And on this Occasion, it will be convenient to intimate to the Reader;

*First*, That the Theories and Discourses here collected, have already past the Censure of the *Learned World*: Who have acknowleg'd them the most satisfactory Accounts of Nature's Proceedings, wherein some of her greatest Depths are fathom'd, and a Foundation laid for Posterity to build an infinite *Superstructure*.

*Secondly*, That they are related (*Verbatim*) just as they were delivered in, or read before the *Royal Society*: For it has been the Opinion of the most Judicious amongst those *Honourable Members*, that it is impossible so to abridge them, (which are but Abridgments themselves) as not to render them obscure and unintelligible.



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# Miſcellanea Curioſa.

## *An Eſtimate of the Quantity of Vapours raiſed out of the Sea, derived from Experiment: Together with an Account of the Circulation of the watry Vapours of the Sea, and of the Cauſe of Springs, preſented to the Royal Society,*

*By Mr.* E. Halley, F. R. S.

THAT the Quantity of Aqueous Vapours contain'd in the Medium of the Air, is very conſiderable, ſeems moſt evident from the great Rains and Snows which are ſometimes obſerv'd to fall, to that degree, that the Water thus diſcharg'd out of the Interſtices of the Particles of Air, is in weight a very ſenſible part of the incumbent Atmoſphere: But in what proportion theſe Vapours riſe, which are the Sources not only of Rains, but alſo of Springs or Fountains (as I deſign to prove) has not, that I know of, been any where well examin'd, tho' it ſeem to be one of the moſt neceſſary Ingredients of a Real and Philoſophical Meteorology, and as ſuch to deſerve the Conſideration of this Ho-



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nourable Society. I thought it might not be unacceptable to attempt by Experiment to determine the Quantity of the Evaporations of Water, as far as they arise from Heat, which upon Trial succeeded as follows.

We took a Pan of Water, about 4 Inches deep, and 7 Inches $\frac{9}{10}$ Diameter, in which we placed a Thermometer, and by means of a Pan of Coals, we brought the Water to the same degree of Heat, which is observed to be that of the Air in our hottest Summer; the Thermometer nicely shewing it: This done, we affixed the Pan of Water, with the Thermometer in it, to one end of the Beam of a Pair of Scales, and exactly counterpois'd it with weights in the other Scale; and by the application or removal of the Pan of Coals, we found it very easie to maintain the Water in the same degree of Heat precisely. Doing thus we found the weight of the Water sensibly to decrease; and at the end of two hours we observed that there wanted half an ounce *Troy*, all but 7 grains, or 233 grains of Water, which in that time had gone off in Vapour; tho' one could hardly perceive it smoke, and the Water were not sensibly warm. This Quantity in so short a time seemed very considerable, being little less than 6 ounces in 24 hours, from so small a Surface as a Circle of 8 Inches Diameter. To reduce this Experiment to an exact Calculus, and determine the thickness of the Skin of Water that had so evaporated, I assume the Experiment alledged by Dr. *Edward Bernard* to have been made in the *Oxford* Society, *viz.* That the Cube-foot English of Water weighs exactly 76 Pounds *Troy*; this divided by 1728, the number of Inches in a Foot, will give 253$\frac{1}{2}$ grains or $\frac{1}{2}$ ounce

Ounce 13½ grains for the weight of a Cube-inch of Water; wherefore the weight of 233 grains is $\frac{233}{233}$ or 35 Parts of 38 of a Cube-inch of Water. Now the Area of the Circle whose Diameter is $7\frac{9}{10}$ Inches, is 49 square Inches; by which dividing the Quantity of Water evaporated, *viz.* $\frac{35}{38}$ of an Inch, the Quote $\frac{35}{1862}$ or $\frac{1}{53}$ shews that the thickness of the Water evaporated was the 53d part of an Inch; but we will suppose it only the 60th part, for the Facility of Calculation. If therefore Water as warm as the Air in Summer, exhales the thickness of a 60th part of an Inch in two hours from its whole Surface, in 12 hours it will exhale the $\frac{1}{10}$ of an Inch; which Quantity will be found abundantly sufficient to serve for all the Rains, Springs, and Dews; and acount for the *Caspian* Sea, being always at a stand, neither wasting nor overflowing; as likewise for the Current said to set always in at the Streights of *Gibralter*, tho' those Mediterranean Seas receive so many and so considerable Rivers.

To estimate the Quantity of Water arising in Vapours out of the Sea, I think I ought to consider it only for the time the Sun is up, for that the Dews return in the night, as much if not more Vapours than are then emitted; and in Summer the Days being longer than 12 hours, this Excess is ballanced by the weaker Action of the Sun, especially when rising before the Water be warmed: So that if I allow $\frac{1}{10}$ of an Inch of the Surface of the Sea, to be raised *per diem* in Vapours, it may not be an improbable Conjecture.

Upon this Supposition, every 10 square Inches of the Surface of the Water, yields in Vapour *per diem* a Cube-inch of Water; and each square Foot half a Wine-pint; every Space of 4 Foot



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ſquare, a Gallon; a Mile ſquare, 6914 Tons; a ſquare Degree ſuppoſe of 69 Engliſh Miles, will evaporate 33 Millions of Tons: And if the Mediterranean be eſtimated at forty degrees long and four broad, allowances being made for the Places where it is broader, by thoſe where it is narrower (and I am ſure I gueſs at the leaſt) there will be 160 Square degrees of Sea; and conſequently, the whole Mediterranean muſt loſe in Vapour, in a Summer's day, at leaſt 5280 Millions of Tons. And this Quantity of Vapour, tho' very great, is as little as can be concluded from the Experiment produced: And yet there remains another Cauſe, which cannot be reduced to Rule, I mean the Winds, whereby the Surface of the Water is licked up ſome times faſter than it exhales by the heat of the Sun; as is well known to thoſe that have conſidered thoſe drying Winds which blow ſometimes.

To eſtimate the Quantity of Water, the Mediterranean Sea receives from the Rivers that fall into it; is a very hard Task, unleſs one had the Opportunity to meaſure their Chanels and Velocity; and therefore we can only do it by allowing more than enough; that is, by aſſuming theſe Rivers greater than in all probability they be, and then comparing the Quantity of Water voided by the *Thames*, with that of thoſe Rivers whoſe Waters we deſire to compute.

The Mediterranean receives theſe conſiderable Rivers; the *Iberus*, the *Rhone*, the *Tiber*, the *Po*, the *Danube*, the *Neiſter*, the *Boryſtenes*, the *Tanais*, and the *Nile*; all the reſt being of no great Note, and their Quantity of Water inconſiderable: Theſe nine Rivers, we will ſuppoſe

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ſuppoſe each of them to bring down ten times as much Water as the River *Thames*; not that any of them is ſo great in reality, but to comprehend with them all the ſmall Rivulets that fall into the Sea, which otherwiſe I know not how to allow for.

To calculate the Water of the *Thames*, I aſſume that at *Kingſton* Bridge where the Flood never reaches, and the Water always runs down, the breadth of the Chanel is 100 Yards, and its Depth 3, it being reduced to an Equality (in both which Suppoſitions I am ſure I take with the moſt) hence the Profil of the Water in this Place is 300 ſquare Yards: This multiplied by 48 Miles (which I allow the Water to run in 24 hours, at 2 Miles an hour) or 84480 Yards, gives 25344000 Cubick-yards of Water to be evacuated every day; that is, 20300000 Tons *per diem*; and I doubt not, but in the exceſs of my Meaſures of the Chanel of the River, I have made more than ſufficient allowance for the Waters of the *Brent*, the *Wandel*, the *Lea*, and *Darwent*, which are all worth notice, that fall into the *Thames* below *Kingſton*.

Now if each of the aforeſaid 9 Rivers yield 10 times as much Water as the *Thames* doth, 'twill follow that each of them yields but 203 Millions of Ton *per diem*, and the whole 9 but 1827 Million of Tons in a day; which is but little more than $\frac{1}{3}$ of what is proved to be raiſed in Vapour out of the Mediterranean in 12 hours time. Now what becomes of this Vapour when rais'd, and how it comes to paſs that the Current always ſets in at the Mouth, of the Streights of *Gibralter*, ſhall immediately be ſhew'd: But firſt it is neceſſary to adver-



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tiſe the Reader, that in making the Experiment herein mention'd, the Water uſed: had been ſalted to the ſame degree as is the common Sea-water, by the Solution of about a 40th part of Salt.

HAving thus ſhew'd by Experiment the Quantity of Water raiſed in Vapour from the Surface the Sea in a Days time, which was ſo far approved of by ſome Honourable Members of this Society, that I received their Commands to proſecute theſe Enquiries; and particularly, in relation to the Method uſed by Nature, to return the ſaid Vapours again into the Sea; which is ſo juſtly performed, that in many hundred of Years we are ſufficiently aſſured that the Sea has not ſenſibly decreaſed by the loſs in Vapour; nor yet abounded by the immenſe Quantity of freſh it receives continually from the Rivers. To demonſtrate this Equilibre of Receipt and Expence in the whole Sea is a Task too hard for me to undertake, yet in obedience to thoſe whom I have the Honour to ſerve, I ſhall here offer, what to me has hitherto ſeem'd the moſt ſatisfactory Account of this grand *Phænomenon*: I have in another place attempted to explain the manner of the riſing of Vapour by Warmth, by ſhewing, that if an Atom of Water were expanded into a Shell or Bubble, ſo as to be ten times as big in Diameter as when it was Water; ſuch an Atom would become ſpecifically lighter than Air, and riſe ſo long as that *Flatus* or warm Spirit that firſt ſeparated it from the Maſs of Water, ſhall continue to diſtend it to the ſame Degree; and that warmth declining, and the Air growing cooler and with alſo ſpecifically lighter, the Vapours conſequently

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quently ſhall ſtop at a certain Region of the Air, or elſe deſcend, which may happen upon ſeveral accounts, as I ſhall by and by endeavour to make out; yet I undertake not that this is the only principal of the riſe of Vapours, and that there may not be a certain ſort of Matter whoſe *Conatus* may be contrary to that of Gravity; as is evident in Vegitation, wherein the Tendency of the Sprouts is directly upwards, or againſt the Perpendicular. But whatever is the true Cauſe, it is in Fact certain, that warmth does ſeparate the Particles of Water, and emit them with a greater and greater Velocity, as the heat is more and more intenſe; as is evident in the Steam of a boiling Cauldron, wherein likewiſe the Velocity of the aſcent of the Vapours does viſibly decreaſe till they diſappear, being diſperſed into and aſſimulated with the Ambient Air. Vapours being thus raiſed by warmth, let us for a firſt Suppoſition put, that the whole Surface of the Globe were all Water very deep, or rather that the whole Body of the Earth were Water, and that the Sun had his diurnal courſe about it: I take it, that it would follow, that the Air of it ſelf would imbibe a certain Quantity of aqueous Vapors, and retain them like Salts diſſolved in Water; that the Sun warming the Air, and raiſing a more plentiful Vapour from the Water in the day-time, the Air would ſuſtain a greater proportion of Vapour, as warm Water will hold more diſſolved Salts, which upon the abſence of the Sun in the Nights would be all again diſcharg'd in Dews, analogous to the Precipitation of Salts on the cooling of the Liquors; nor is it to be believed that in ſuch Caſe there would be any diverſity of Weather, other than

periodically, every Year alike; the mixture of all terrestrious, saline, heterogenious Vapours being taken away, which as they are variously compounded and brought by the Winds, seem to be the Causes of those various Seasons which we now find. In this case the Aiery Regions every where, at the same height, would be equally repleniſhed with the Proportion of Water it could contain, regard being only to be had to the different degree of warmth, from the nearneſs or diſtance of the Sun; and an eternal East-wind would blow all round the Globe, inclining only to the same side of the *East*, as the Latitude doth from the Equator; as is obſerved in the Ocean between the Tropicks.

Next let us suppoſe this Ocean iuterſperſed with wide and ſpacious Tracts of Land, with high Ridges of Mountains, ſuth as the *Pyrenean*, the *Alps*, the *Apennine*, the *Carpathian* in *Europe*, *Taurus Caucaſus Imaus*, and ſeveral others in *Aſia*; *Atlas* and the *Montes Lunæ*, with other unknown Rridges in *Africa*, whence came the *Nile*, the *Nigre*, and the *Zaire*: And in *America*, the *Andes* and the *Apalatean* Mountains; each of which far ſurpaſs the uſual height to which the Aqueous Vapours of themſelves aſcend, and on the tops of which the Air is ſo cold and rarified, as to retain but a ſmall part of thoſe Vapours that ſhall be brought thither by Winds. Thoſe Vapours therefore that are raiſed copiouſly in the Sea, and by the Wind, are carried over the low Land to thoſe Ridges of Mountains, are there compelled by the Stream of the Air to mount up with it to the tops of the Mountains, where the Water preſently precipitates, gleeting down by the Crannies of the Stone; and part of the Vapour entering into the Caverns

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verns of the Hills, the Water thereof gathers as in an Alembick into the Basons of Stone it finds; which being once fill'd, all the overplus of Water that comes thither runs over by the lowest place, and breaking out by the sides of the Hills, forms single *Springs*. Many of these running down by the Valleys or Guts between the ridges of the Hills, and coming to unite form little Rivulets, or Brooks: many of these again, meeting in one common Valley and gaining the plain Ground, being grown less rapid become a River: and many of these being united in one common Channel, make such Streams as the *Rhine*, the *Rhone*, the *Danube*, which latter, one would hardly think the Collection of Water condensed out of Vapour, unless we consider how vast a Tract of Ground that River drains, and that it is the Sum of all those Springs which break out on the South side of the *Carpathian* Mountains, and on the North side of the immense Ridge of the *Alps*, which is one continued Chain of Mountains from *Switzerland*, to the *Black-Sea*. And it may almost pass for a Rule, that the magnitude of a River, or the quantity of Water it evacuates, is proportionable to the length and height of the Ridges from whence its Fountains arise. Now this Theory of *Springs* is not a bare *Hypothesis*, but founded ion Experience, which it was my luck to gain tn my abode at St. *Helena*, where in the Night ime, on the tops of the Hills, about 800 Yards above the Sea, there was so strange a condenation, or rather precipitation of the Vapours, that it was a great Impediment to my Cœlestial Observations; for in the clear Sky, the Dew would fall so fast, as to cover each half quarter of an Hour, my Glasses with little drops, so that

that it I was neceſſitated to wipe them ſo often, and my Paper on which I wrote my Obſervations would immediately be ſo wet with Dew, that it would not bear Ink: By which it may be ſuppos'd how faſt the Water gathers in thoſe mighty high Ridges I but now nam'd.

Thus is one part of the Vapours blown upon the Land return'd by the Rivers into the Sea, from whence they came; another part by the cool of the Night falls in Dews, or elſe in Rains, again into the Sea before it reaches the Land, which is by much the greateſt part of the whole Vapours, becauſe of the great extent of the Ocean, which the motion of the Winds does not traverſe in a very long ſpace of Time; and this is the Reaſon why the Rivers do not return ſo much into the *Mediterranean*, as is extracted into Vapour. A third part falls on the Low-Lands, and is the *Pabulum* of Plants, where yet it does not reſt, but is again exhaled in Vapour by the action of the Sun, and is either carried by the Winds to the Sea to fall in Rain or Dew there, or elſe to the Mountains to be there turn'd into Springs; and tho' this does not immediately come to paſs, yet after ſeveral Viciſſitudes of riſing in Vapour, and falling in Rain or Dews, each Particle of the Water is at length return'd to the Sea from whence it came. Add to this, that the Rain-waters after the Earth is fully ſated with moiſture, does, by the Vallies or lower parts of the Earth, find its way into the Rivers, and ſo is compendiouſly ſent back to the Sea. After this manner is the Circulation perform'd, and I doubt not but this Hypotheſis is more reaſonable than that of thoſe who derive all Springs from the Rain-waters, which yet are perpetual and without diminution, even when

when no Rain falls for a long space of time; or that derive them from a Filtration or Percolation of the Sea-waters, tho' certain imaginary Tubes or Passages within the Earth wherein they lose their Saltness. This, besides many others, labouring under this principal Absurdity, that the greatest Rivers have their most copious Fountains fartheſt from the Sea, and whether so great quantities of fresh Water cannot reasonably be deriv'd any other way than in Vapour. This, if we may allow final Causes, seems to be the design of the Hills that their Ridges being plac'd thro' the midst of the Continents, might serve, as it were, for Alembicks to distil fresh Water for the use of Man and Beast, and their heights to give a descent to those Streams to run gently, like so many Veins of the *Macrocosm* to be the more benificial to the Creation. If the difference between Rain and Dew, and the cause why sometimes 'tis Cloudy, at other times Serene, be inquir'd, I can offer nothing like a proper Solution thereof, only with submission to propose Conjectures, which are the best I can find, *viz.* That the Air being heaped up by the meeting of two contrary Winds, when the *Mercury* is high, the Vapours are the better sustain'd and kept from Co-agulating or Condensing into Drops, whereby Clouds are not so easily generated; and in the Night the Vapours fall down single, as they arose in imperceptible Atoms of Water: Whereas, when the *Mercury* is low and the Air rarified by the Exhaustion thereof, by two contrary Winds blowing from the place; the Atoms of Air keep the Vapours not so well separated, and they Coalesce into visible Drops in the Clouds, and from thence

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are eaſily drawn into greater Drops of Rain; to which 'tis poſſible and not improbable, that ſome ſort of Saline or Angular Particles of Terreſtrial Vapour being immix'd with the Aqueous, which I take to be Bubbles, may cut or break their Skins or Coats, and ſo contribute to their more ſpeedy Condenſation into Rain.

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*The*

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## *The True Theory of the Tides, extracted from that admired Treatise of Mr.* Isaac Newton, *Intituled,* Philosophiæ Naturalis Principia Mathematica; *being a Discourse presented with that Book to the late King* James, *by Mr.* Edmund Halley.

*IT may, perhaps, seem strange, that this Paper, being no other than a partile Account of a Book long since published, should now appear here; but the Desire of several honourable Persons, which could not be withstood have obliged us to insert it here, for the sake of such, who being less knowing in Mathematical Matters; and therefore not daring to adventure on the Author himself, are notwithstanding, very curious to be informed of the Causes of Things; particularly of so general and extraordinary* Phænomena, *as are those of the Tides. Now this Paper having been drawn up for the late King* James's *Use, (in whose Reign the Book was published) and having given good Satisfaction to those that got Copies of it; it is hoped the Savans of the higher Form will indulge us this Liberty we take to gratifie their Inferiours in point of Science; and not be offended, that we here insist more largely upon Mr.* Newton's Theory of the Tides, *which, how plain and easie soever we find, is very little understood by the common Reader.*

THE

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THE sole Principle upon which this Author proceeds to explain most of the great and surprizing Appearances of Nature, is no other then that of *Gravity*, whereby in the Earth all Bodies have a tendency towards its Centre; as is most evident: and from undoubted Arguments its proved, that there is such a Gravitation towards the Centre of the Sun, Moon, and all the Planets.

From this Principle, as a necessary Consequence, follows the Sphærical Figure of the Earth and Sea, and of all the other Cælestial Bodies: and tho' the tenacity and firmness of the Solid Parts, support the Inequalities of the Land above the Level; yet the Fluids, pressing equally and easily yielding to each other, soon restore the *Æquilibrium*, if disturbed, and maintain the exact Figure of the Globe.

Now this force of Descent of Bodies towards the Center, is not in all places alike, but is still less and less, as the distance from the Center encreases: and in this Book it is demonstrated, that this Force decreases as the Square of the distance increases; that is, the weight of Bodies and the force of their Fall is less, in parts more removed from the Center, in the proportion of the Squares of the Distance. So as for Example, a Ton weight on the Surface of the Earth, if it were raised to the height of 4000 Miles, which I suppose the Semidiameter of the Earth, would weigh but $\frac{1}{4}$ of a Ton, or 5 Hundred weight: If to 12000 Miles, or 3 Semidiameters from the Surface, that is 4 from the Center, it would weigh but $\frac{1}{16}$ part of the Weight on the Surface, or a Hundred and Quarter: So that it would be as easie for the

Strength

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Strength of a Man at that height to carry a Ton weight, as here on the Surface a $100\frac{1}{4}$. And in the same Proportion does the Velocities of the fall of Bodies decrease: For whereas on the Surface of the Earth all things fall 16 Foot in a second, at one Semidiameter above, this fall is but four Foot; and at three Semidiameters, or four from the Centre, it is but $\frac{1}{16}$ of the Fall at the Surface, or but one Foot in a second: And at greater Distances both Weight and Fall become very small, but yet at all given Distances is still some thing, tho' the Effect become insensible. At the distance of the Moon (which I will suppose 60 Semidiameters of the the Earth) 3600 Pounds weigh but one Pound, and the fall of Bodies is but $\frac{1}{3600}$ of a Foot in a second, or 16 Foot in a Minute; that is, a Body so far off descends in a Minute no more than the same at the Surface of the Earth would do in a Second of Time.

As was said before, the same force decreasing after the same manner is evidently found in the Sun, Moon, and all the Planets; but more especially in the Sun, whose Force is prodigious; becoming sensible even in the immense distance of *Saturn*: This gives room to suspect, that the force of Gravity is in the Cœlestial Globes proportional to the quantity of Matter in each of them: And the Sun being at least ten Thousand times as big as the Earth, its Gravitation or attracting Force, is found to be at least ten Thousand times as much as that of the Earth, acting on Bodies at the same distance.

This Law of the decrease of Gravity being demonstratively proved, and put past contradiction; the Author with great Sagacity, inquires into the necessary Consequences of this

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Supposition; whereby he finds the genuine Cause of the several Appearances in the Theory of the Moon and Planets, and discovers the hitherto unknown Laws of the Motion of Comets, and of the Ebbing and flowing of the Sea. Each of which are Subjects that have hitherto taken up much larger Volumes; but Truth being uniform, and always the same, it is admirable to observe how easily we are enabled to make out very abstruse *and difficult Matters*, when once true and genuine Principles are obtained: And on the other hand it may be wondred, that, notwithstanding the great facility of truth, and the perplexity and nonconsequences that always attend erroneous Suppositions, these great Discoveries should have escaped the acute Disquisitions of the best Philosophical Heads of all past Ages, and be reserv'd to these our Times. But that wonder will soon cease, if it be consider'd how great improvements Geometry has receiv'd in our Memory, and particularly from the profound Discoveries of our incomparable Author.

The Theory of the Motion of the primary *Planets* is here shewn to be nothing else, but the contemplation of the Curve Lines which Bodies cast with a given Velocity, in a given Direction and at the same time drawn towards the Sun by its gravitating Power, would describe. Or, which is all one, that the Orbs of the Planets are such Curve Lines as a Shot from a Gun describes in the Air, being cast according to the direction of the Piece, but bent in a crooked Line by the supervening Tendency towards the Earths Centre: And the Planets being supposed to be projected with a given Force, and attracted towards the Sun, after the aforesaid man-

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manner, are here proved to deſcribe ſuch Figures, as anſwer punctually to all that the Induſtry of this and the laſt Age has obſerv'd in the Planetary Motions. So that it appears, that there is no need of ſolid Orbs and Intelligences, as the Antients imagin'd, nor yet of *Vortices* or Whirlpools of the Celeſtial Matter, as *Des Cartes* ſuppoſes; but the whole Affair is ſimply and mechanically performed, upon the ſole Suppoſition of a Gravitation towards the Sun; which cannot be denied.

The Motion of *Comets* is here ſhewn to be compounded of the ſame Elements, and not to differ from Planets, but in their greater ſwiftneſs, whereby overpowering the Gravity that ſhould hold them to the Sun, as it doth the Planets, they fly off again, and diſtance themſelves from the Sun and Earth, ſo that they ſoon are out of our ſight. And the imperfect Accounts and Obſervations Antiquity has left us, are not ſufficient to determine whether the ſame Comet ever return again. But this Author has ſhewn how Geometrically to determine the Orb of a Comet from Obſervations, and to find his diſtance from the Earth and Sun, which was never before done.

The third thing here done is the Theory of the Moon, all the Inequalities of whoſe Motion are proved to ariſe from the ſame Principles, only here the effect of two Centers operating on, or attracting a projected Body comes to be conſidered; for the Moon, tho principally attracted by the Earth, and moving round it, does together with the Earth, move round the Sun once a Year, and is according as ſhe is, nearer or farther from the Sun, drawn by him more or leſs than the Center of the Earth, about



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which ſhe moves; whence ariſe ſeveral Irregularities in her Motion, of all which, the Author in this Book, with no leſs Subtility than Induſtry, has given a full account. And tho' by reaſon of the great Complication of the Problem, he has not yet been able to make it purely Geometrical, 'tis to be hoped, that in ſome farther Eſſay he may ſurmount the difficulty: And having perfected the Theory of the Moon, the long deſir'd diſcovery of the Longitude (which at Sea is only practicable this way) may at length be brought to light, to the great Honour of your Majeſty and Advantage of your Subjects.

All the ſurprizing Phænomena of the Flux and Reflux of the Sea, are in like manner ſhewn to proceed from the ſame Principle; which I deſign more largely to inſiſt on, ſince the matter of Fact is in this caſe much better known to your Majeſty than in the foregoing.

If the Earth were alone, that is to ſay, not affected by the Actions of the Sun and Moon, it is not to be doubted, but the Ocean, being equally preſs'd by the force of Gravity towards the Center, would continue in a perfect ſtagnation, always at the ſame height, without either Ebbing or Flowing; but it being here demonſtrated, that the Sun and Moon have a like Principle of Gravitation towards their Centers, and that the Earth is within the Activity of their Attractions, it will plainly follow, that the Equality of the preſſure of Gravity towards the Center will thereby be diſturb'd; and tho' the ſmallneſs of theſe Forces, in reſpect of the Gravitation towards the Earths Center, renders them altogether imperceptible

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perceptible by any Experiments we can devise, yet the Ocean being fluid and yeilding to the least force, by its rising shews where it is less prest, and where it is more prest by its sinking.

Now if we suppose the force of the Moons Attraction to decrease as the Square of the Distance from its Center increases (as in the Earth and other Celestial Bodies) we shall find, that where the Moon is perpendicularly either above or below the Horizon, either in Zenith or Nadir, there the force of Gravity is most of all diminished, and consequently that there the Ocean must necessarily swell by the coming in of the Water from those parts where the Pressure is greatest, *viz.* in those places where the Moon is near the Horizon: But that this may be the better understood, I thought it needful to add the following Figure, (*Vide Fig.* 1. *Plate* 1.) where *M* is the Moon, *E* the Earth, *C* its Center, and *Z* the place where the Moon is in the Zenith, *N* where in the Nadir.

Now, by the Hypothesis it is evident, that the Water in *Z*, being nearer, is more drawn by the Moon, than the Center of the Earth *C*, and that again more than the Water in *N*, wherefore the Water in *Z* hath a tendency towards the Moon, contrary to that of Gravity, being equal to the excess of the Gravitation in *Z*, above that in *C*. And in the other case, the Water in *N*, tending less towards the Moon than the Center *C*, will be less pressed, by as much as is the difference of the Gravitations towards the Moon in *C* and *N*. This rightly understood, it follows plainly, that the Sea, which otherwise would be Spherical, upon the Pressure of the Moon, must form it

ſelf into a Spheroidal or Oval Figure, whoſe longeſt Diameter is where the Moon is vertical, and ſhorteſt where ſhe is in the Horizon; and that the Moon ſhifting her Poſition as ſhe turns round the Earth once a Day, this Oval of Water ſhifts with her, occaſioning thereby the two Floods and Ebbs obſervable in each 25 Hours.

And this may ſuffice as to the general Cauſe of the Tides; it remains now to ſhew how naturally this motion accounts for all the Particulars that have been obſerv'd about them; ſo that there can be no room left to doubt, but that this is the true cauſe thereof.

The Spring Tides upon the New and Full Moons, and Neap Tides on the Quarters, are occaſion'd by the attractive Force of the Sun in the New and Full, conſpiring with the Attraction of the Moon, and producing a Tide by their united Forces: Whereas in the Quarters, the Sun raiſes the Water where the Moon depreſſes it, and the contrary; ſo as the Tides are made only by the difference of their Attractions. That the force of the Sun is no greater in this caſe, proceeds from the very ſmall Proportion the Semidiameter of the Earth bears to the vaſt diſtance of the Sun.

It it alſo obſerv'd, that *cæteris paribus*, the Æquinoctial Spring Tides in *March* and *September*, or near them, are the Higheſt, and the Neap Tides the loweſt; which proceeds from the greater Agitations of the Waters, when the fluid *Spheroid* revolves about a great Circle of the Earth, than when it turns about in a leſſer Circle; it being plain, that if the Moon were conſtituted in the Pole and there ſtood, that the *Spheroid* would have a fixt Po-

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sition, and that it would be always high Water under the Poles, and low Water every where under the Æquinoctial: And therefore the nearer the Moon approaches the Poles, the less is the agitation of the Ocean, which is of all the greatest, when the Moon is in the Æquinoctial, or fartheſt distant from the Poles. Whence the Sun and Moon, being either conjoined or oppoſite in the Æquinoctial, produce the greateſt Spring Tides; and the ſubſequent Neap Tides, being produc'd by the Tropical Moon in the Quarters, are always the leaſt Tides; whereas in *June* and *December*, the Spring Tides are made by the Tropical Sun and Moon, and therefore leſs vigorous; and the Neap Tides by the Æquinoctial Moon, which therefore are the ſtronger: Hence it happens, that the difference between the Spring and Neap Tides in theſe Months, is much leſs conſiderable than in *March* and *September*. And the reaſon why the very higheſt Spring Tides are found to be rather before the Vernal and after the Autumnal Equinox, *viz.* in *February* and *October*, than preciſely upon them, is, becauſe the Sun is nearer the Earth in the Winter Months, and ſo comes to have a greater effect in producing the Tides.

Hitherto we have conſider'd ſuch Affections of the Tides as are Univerſal, without relation to particular Caſes; what follows from the differing Latitudes of places, will be eaſily underſtood by the following Fig. (*Vide Fig.* 2. *Plate* 1.)

Let *A p E P* be the Earth cover'd over with very deep Waters, *C* its Center, *P*, *p*, its Poles, *A E* the Æquinoctial, *F f* the parallel of Latitude of a Place, *D d* another Parallel at equal diſtance on the other ſide of the Æqui-



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noctial, *H h* the two Points where the Moon is vertical, and let *K k* be the great Circle, wherein the Moon appears Horizontal. It is evident, that a Spheriod describ'd upon *H h*, and and *K k* shall nearly represent the Figure of the Sea, and *Cf*, *CD*, *CF*, *Cd* shall be the hights of the Sea in the places *f*, *D*, *F*, *d*, in all which it is High-water: And seeing that in twelve Hours time, by the diurnal Rotation of the Earth, the Point *F* is transferr'd to *f*, and *d* to *D*: The hight of the Sea *CF* will be that of the High-water when the Moon is present, and *Cf* that of the other High-water, when the Moon is under the Earth: Which in the case of this Figure is less than the former *CF*. And in the opposite Parallel *D d* the contrary happens. The Rising of the Water being always alternately greater and less in each place, when it is produc'd by the Moon declining sensibly from the Æquinoctial; that being the greatest of the two High-waters in each diurnal Revolution of the Moon, wherein she approaches neareſt either to the Zenith or Nadir of the place: Whence it is that the Moon in the Northern Signs, in this part of the World, makes the greatest Tides when above the Earth, and in Southern Signs, when under the Earth; the Effect being always the greatest where the Moon is fartheſt from the Horizon, either above or below it. And this alternate increase and decrease of the Tides has been observ'd to hold true on the Coast of *England*, at *Bristol* by Capt. *Sturmy*, and at *Plymouth* by Mr. *Colepresse*.

But the motions hitherto mention'd are somewhat alter'd by the Libration of the Water, whereby, tho' the Action of the *Lumina-*

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*ries* should cease, the Flux and Reflux of the Sea would for some time continue: This Conservation of the impress'd Motion diminishes the differences that otherwise would be between two consequent Tides, and is the reason why the highest Spring-Tides are not precisely on the New and Full Moons, nor the Neaps on the Quarters; but generally they are the third Tides after them, and sometimes later.

All these things would regularly come to pass, if the whole Earth were cover'd with Sea very deep; but by reason of the shoalness of some places, and the narrowness of the Streights, by which the Tides are in many cases propagated, there arises a great diversity in the Effect, and not to be accounted for, without an exact Knowledge of all the Circumstances of the Places, as of the Position of the Land, and the Breadth and Depth of the Channels by which the Tide flows; for a very slow and imperceptible motion of the whole Body of the Water, where it is (for example) 2 Miles deep, will suffice to raise its Surface 10 or 12 Feet in a Tides time; whereas, if the same quantity of Water were to be convey'd upon a Channel of 40 Fathoms deep, it would require a very great Stream to effect it, in so large Inlets as are the Channel of *England* and the *German* Ocean; whence the Tide is found to set strongest in those places where the Sea grows narrowest; the same quantity of Water being to pass through a smaller Passage: This is most evident in the *Streights*, between *Portland* and *Cape de Hague* in *Normandy*, where the Tide runs like a Sluce; and would be yet more between *Dover* and *Calis*, if the Tide coming a-



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bout the Island from the North did not check it. And this force being once impress'd upon the Water, continues to carry it above the level of the ordinary height in the Ocean, particularly where the Water meets a direct Obstacle, as it is at St. *Malo*'s; and where it enters into a long Channel, which running far into the Land, grows very streight at its Extremity; as it is in the *Severn-Sea* at *Chepstow* and *Bristol*.

This shoalness of the Sea and the intercurrent Continents are the reason, that in the open Ocean the time of High-water is not at the Moons appulse to the Meridian, but always some Hours after it; as it is observ'd upon all the West-Coast of *Europe* and *Africa*, from *Ireland* to the *Cape of Good-Hope*: In all which a S. W. Moon makes High-water, and the same is reported to be on the West side of *America*. But it would be endless to account all the particular Solutions, which are easie Corollaries of this *Hypothesis*; as why the *Lakes*, such as the *Caspian Sea*, and *Mediterranian Seas*, such as the *Black Sea*, the *Streights* and *Baltick*, have no sensible Tides: For *Lakes* having no Communication with the Ocean, can neither increase nor diminish their Water, whereby to rise and fall; and Seas that communicate by such narrow Inlets, and are of so immense an Extent, cannot in a few Hours time receive or empty Water enough to raise or sink their Surface any thing sensibly.

Lastly, to demonstrate the excellency of this Doctrine, the Example of the Tides in the Port of *Tunking* in *China*, which are so extraordinary, and differing from all others we have yet heard of, may suffice. In this Port there is but

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but one Flood and Ebb in 24 Hours; and twice in each Month, *viz.* when the Moon is near the Æquinoctial there is no Tide at all, but the Water is stagnant; but with the Moons declination there begins a Tide, which is greatest when she is in the Tropical Signs: Only with this difference, that when the Moon is to the Northward of the Æquinoctial, it Flows when she is above the Earth, and Ebbs when she is under, so as to make High-water at Moons-setting, and Low-water at Moons-rising; But on the contrary, the Moon being to the Southward, makes High-water at rising and Low-water at setting; it Ebbing all the time she is above the Horizon. As may be seen more at large in the *Philosophical Transaction*, Numb. 162.

The Cause of this odd Appearance is propos'd by Mr. *Newton*, to be from the concurence of two Tides; the one propagated in six Hours out of the great *South-Sea* along the Coast of *China*; the other out of the *Indian-Sea*, from between the Islands in twelve Hours, along the Coast of *Malacca* and *Cambodia*. The one of these Tides, being produc'd in North-Latitude, is, as has been said, greater, when the Moon being to the North of the Equator is above the Earth, and less when she is under the Earth. The other of them, which is propagated from the *Indian-Sea*, being raised in South-Latitude, is greater when the Moon declining to the South, is above the Earth, and less when she is under the Earth: So that of these Tides alternately greater and lesser, there comes always successively two of the greater and two of the lesser together every day; and the High-water falls always between the times of the

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the arrival of the two greater Floods; and the Low-water between the arrival of the two lesser Floods. And the Moon coming to the Æquinoctial, and the alternate Floods becoming equal, the Tide ceases and the Water stagnates: But when she has pass'd to the other side of the Equator, those Floods which in the former Order were the least, now becoming the greatest, that That before was the time of High-water now becomes the Low-water, and the Converse. So that the whole appearance of these strange Tides, is without any forcing naturally deduc'd from these Principles, and is a great Argument of the certainty of the whole *Theory*.



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## *A Theory of the* Variation *of the* Magnetical Compass, *by Mr.* Ed. Halley *Fellow of the R. S.*

THE variation of the Compass (by which I mean the deflection of the Magnetical Needle from the true Meridian) is of that great concernment in the Art of Navigation, that the neglect thereof, does little less then render useless one of the noblest Inventions Mankind ever yet attained to. And for this cause all Ships of Consequence (especially those bound beyond the Equator) carry with them Instruments on purpose to observe this variation: That so the Course steer'd by the Compass, may be reduc'd to the true Course in respect of the Meridian.

Now altho' the great utility that a perfect knowledge of the Theory of the Magnetical Direction would afford to Mankind in general, and especially to those concern'd in Sea Affairs, seems as sufficient incitement to all Philosophical and Mathematical Heads, to take under serious Consideration the several *Phenomena*, and to endeavour to reconcile them by some general Rule: Yet so it is; that almost all the Authors, from whom a Discourse of this kind ought to have been expected, pass by in silence the difficulties they here encounter. And those that mention this variation: By affirming it to proceed from Causes altogether uncertain (as are the casual lying of Iron Mines and Loadstones in the Earth) put a stop to all further Contemplation

plation; and give discouragement to those that would otherwise undertake this Enquiry. 'Tis true, that not long since one Mr. *Bond*, an old Teacher of Navigation, put forth a small Treatise wherein he pretends to calculate the variation. But he limits his Hypothesis to the City of *London*, affirming himself (as he had a great deal of reason) that the same *Calculus* is not sufficient for other places; whereby it appears that this Rule is far short of the so much desir'd general one.

Now although (through want of sufficient Observations and some other difficulties which I shall anon shew) I cannot pretend perfectly to establish the Numbers and Rules of a *Calculus* which shall precisely answer to the variations of all parts of the World: Yet I suppose it will not be unacceptable to the curious to propose something of a light into this abstruse Mystery; which, if no other, may have this good effect, to stir up the Philosophical *Genii* of the Age to apply themselves more attentively to this useful speculation. But before I proceed, 'twill be necessary to lay down the Grounds upon which I raise my Conclusions; and at once to give a Synopsis of those variations which I have reason to look upon as sure, being mostly the Observations of Persons of good Skill and Integrity.



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# TABLE OF VARIATIONS.

| *Names of Places.* | *Longitude from Lon.* | *Latitude.* | *Anno Dom.* | *Variation Observ'd.* |
|---|---|---|---|---|
| | d m | d m | | d m |
| *London* | 0 0 | 51 32 N | 1580 | 11 15 E |
| | | | 1622 | 6 0 E |
| | | | 1634 | 4 5 E |
| | | | 1672 | 2 30 W |
| *Paris* | 2. 25 E | 48. 51 N | 1683 | 4 30 W |
| | | | 1640 | 3 00 E |
| | | | 1666 | 0 0 |
| | | | 1681 | 2 30 W |
| *Uraniburg* | 13. 0 E | 55. 54 N | 1672 | 2 35 W |
| *Copenhagen* | 12. 53 E | 55. 41 N | 1649 | 1 30 E |
| | | | 1672 | 3 35 W |
| *Dantzick* | 19. 0. E | 54. 23 N | 1679 | 7 00 W |
| *Mompelier* | 4. 0 E | 43. 37 N | 1674 | 1 10 W |
| *Breft* | 4. 25 W | 48. 23 N | 1680 | 1 45 W |
| *Rome* | 13. 0 E | 41. 50 N | 1681 | 5 0 W |
| *Bayonne* | 1. 20 W | 43. 30 N | 1680 | 1 20 W |
| *Hudſon's Bay* | 79. 40 W | 51 00 N | 1668 | 19 15 W |
| In *Hud.* Straights | 57. 00 W | 61 00 N | 1668 | 28 30 W |
| In *Baffins* Bay at Sir *Thomas Smiths* Sound | 80. 00 W | 78 00 N | 1616 | 57 00 W |



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| *Names of Places.* | *Longitude.* | | | *Latitude.* | | | *Anno Dom.* | *Variation* | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *d* | *m* | | *d* | *m* | | | *d* | *m* | |
| At Sea | 50 | 0 | W | 38 | 40 | N | 1682 | 7 | 30 | W |
| At Sea | 31 | 30 | W | 43 | 50 | N | 1682 | 5 | 30 | W |
| At Sea | 42 | 0 | W | 21 | 0 | N | 1678 | 0 | 40 | E |
| Cape St. *Aug.* of *Brazile* | 35 | 30 | W | 8 | 0 | S | 1670 | 5 | 30 | E |
| Cape Frio | 41 | 10 | W | 22 | 40 | S | 1670 | 12 | 10 | E |
| At Sea off of the Mou. of the River of *Plate* | 53 | 00 | W | 39 | 30 | S | 1670 | 20 | 30 | E |
| At the East Entrance of *Magellan* Straits | 68 | 00 | W | 52 | 30 | S | 1670 | 17 | 00 | E |
| At the W. Entrance of the *Magellan* Straits | 75 | 00 | W | 53 | 00 | S | 1670 | 14 | 10 | E |
| *Baldivia* | 73 | 00 | W | 40 | 00 | S | 1670 | 8 | 10 | E |
| At Cape d' *Agulhas* | 16 | 30 | E | 34 | 50 | S | 1622 | 2 | 00 | W |
| | | | | | | | 1675 | 8 | 00 | W |
| At Sea | 1 | 0 | E | 34 | 30 | S | 1675 | 0 | 0 | |
| At Sea | 20 | 0 | W | 34 | 0 | S | 1675 | 10 | 30 | E |
| At Sea | 32 | 0 | W | 24 | 0 | S | 1675 | 10 | 30 | E |
| At St. *Helens* | 6 | 30 | W | 16 | 0 | S | 1677 | 0 | 40 | E |
| At *Ascension* | 14 | 30 | W | 7 | 50 | S | 1678 | 1 | 00 | E |
| At *Johanna* | 44 | 00 | E | 12 | 15 | S | 1675 | 19 | 30 | W |
| At *Monbasa* | 40 | 00 | E | 4 | 00 | S | 1675 | 16 | 00 | W |
| At *Zocatra* | 56 | 00 | E | 12 | 30 | N | 1674 | 17 | 00 | W |
| At *Aden*, at the M. of the *Red Sea* | 47 | 30 | E | 13 | 00 | N | 1674 | 15 | 00 | W |
| At *Diego Rois* | 61 | 0 | E | 20 | 0 | S | 1676 | 20 | 30 | W |
| At Sea | 64 | 30 | E | 0 | 0 | | 1676 | 15 | 30 | W |
| At Sea | 55 | 0 | E | 27 | 0 | S | 1676 | 24 | 00 | W |
| At *Bombay* | 72 | 30 | E | 19 | 0 | N | 1676 | 12 | 00 | W |
| At Cape *Comorin* | 76 | 00 | E | 8 | 15 | N | 1680 | 8 | 48 | W |
| At *Billifore* | 87 | 00 | E | 21 | 30 | N | 1680 | 8 | 20 | W |
| At Fort St. *George* | 80 | 00 | E | 13 | 15 | N | 1680 | 8 | 10 | W |
| At the W. point of *Java* | 104 | 0 | E | 6 | 40 | S | 1676 | 3 | 10 | W |

At

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| At Sea | 58 | 00 | E | 39 | 0 | S | 1677 | 27 | 30 | W |
| At the Isle of St. *Paul* | 74 | 0 | E | 38 | 0 | S | 1677 | 23 | 30 | W. |
| At *Van Diemens* Land | 142 | 0 | E | 42 | 25 | S | 1642 | 0 | 0 | |
| At new *Zealand* | 170 | 0 | E | 40 | 50 | S | 1642 | 9 | 0 | E |
| At Three Kings Isle in New *Zeland* | 169 | 30 | E | 34 | 35 | S | 1642 | 8 | 40 | E |
| At the Isle *Rotterdam* in the South Sea | 184 | 00 | E | 20 | 15 | S | 1642 | 6 | 20 | E |
| on the Coast of *N. Guniea* | 149 | 00 | E | 4 | 30 | S | 1643 | 8 | 45 | E |
| at the W. p. of *N. Guniea* | 126 | 00 | E | 0 | 26 | S | 1643 | 5 | 30 | E |

Tho' I could wish we could obtain from the *Spaniards* what Variations they find in their Voyages from the *Manilhas* towards *Acapulco*, thorough the North part of the South Sea; as likewise what it is at *Japan*, from the *Dutch*: Yet (considering the number of these Observations I have collected, and that they are made in parts of the World so remote from *Europe*, and from one another) I suppose that the Theory that answers these will scarce fail in those Regions from whence we have as yet no account. But first we must make some remarkes upon the foregoing Table: And, First,

That in all *Europe* the variation at this time is *West*, and more in the Eastern Parts thereof than the Western: As likewise that it seems throughout to be upon the increase that way.

Secondly, That on the Coast of *America*, about *Virginia*, *New-England* and *New-found-Land*, the variation is likewise Westerly; and that it increases all the way as you go Northerly along the Coast so as to be above 20 Degrees at *New-found-Land*, nearly 30 gr. in *Hudsons Straits*, and not less than 57 Degrees in

*Baffins*

*Baffins Bay*; also, that as you Sail Eastward from this Coast the variation diminishes. From these two it is a Legitimate Corallary: That *Somewhere between* Europe, *and the North part of* America, *there ought to be an Easterly Variation, or at least no Westerly.* And so I conjecture it is about the Eastermost of the *Tercera Islands.*

Thirdly, That on the Coast of *Brasile* there is East variation, which increases very notably as you go to the Southward so as to be 12 Degrees at *Cape Frio*, and over against the River of *Plate* 20½ Degrees: And from thence Sailing Southwesterly to the Straits of *Magellan* it decreases 17 Degrees, and at the West Entrance but 14 Degrees.

Fourthly, That at the Eastward of *Brasile* properly so called, this Easterly variation decreases, so as to be very little at St. *Helena* and *Ascension*, and to be quite gone and the Compass Point true about 18 Degrees of Longitude West from the Cape of *Good-hope.*

Fifthly, That to the Eastward of the aforesaid Places a Westward variation begins, which Reigns in the whole *Indian* Sea, and arises to no less than Eighteen Degrees under the Equator itself, about the Meridian of the Northern part of *Madagascar*; and near the same Meridian but in 39. Degrees South Latitude it is found full 27½ Degrees: From thence Easterly the West variation decreases, so as to be little more than eight Degrees at *Cape Comorin*, and than three Degrees upon the Coast of *Java*; and to be quite extinct about the *Molucca Islands*, as also a little to the Westwards of *Van Diemens*

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*Diemens* Land found out by the *Dutch* in 1642.

Sixthly, That to the Eastward of the *Molucca*'s and *Van Diemens* Land in South Latitude there arises another Easterly Variation, which seems not so great as the former, nor of so large extent; for that at the Island *Rotterdam* it is sensibly less than upon the East Coast of *New Guinea*; and, at the rate it decreases, it may well be suppos'd, that about 20 Degrees farther East or 225 Degrees East Longitude from *London*, in the Latitude of 20 Degrees South, a Westerly Variation begins.

Seventhly, That the variations observ'd by the Honourable Sir *John Norborough* at *Baldivia* and at the West Entrance of the *Straights* of *Magellan* do plainly shew, that That East variation, noted in our third Remark, is decreasing apace; and that it cannot reasonably extend many Degrees into the South Sea from the Coast of *Peru* and *Chili*, leaving room for a small Westerly variation, in that Tract of the unknown World that lies in the mid-Way between *Chili* and *New-Zealand*, and between *Hounds-Island* and *Peru*.

Eighthly, That in Sailing North-West from St. *Helena* by *Ascension* as far as the Equator the variation continues very small East, and as it were constantly the same: So that in this part of the World the Course, wherein there is no variation, is evidently no Meridian, but rather North-West.

Ninthly, That the Entrance of *Hudson*'s *Straights* and the Mouth of the River of *Plate* being nearly under the same Meridian, at the



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one place the Needle varies 29½ Degrees to the *West*; at the other 20½ Degrees to the *East*. This plainly demonstrates the impossibility of reconciling these variations by the Theory of *Bond*; *which is by two Magnetical Poles and an Axis, inclined to the Axis of the Earth*; from whence it would follow, That *under the same Meridian the Variation should be in all places the same way.*

These things being premised may serve as a sure Foundation to raise the superstructure of a Theory upon. But first it would not be amiss to shew hereby the mistake of *Gilbert* and *Des Cartes*: The first whereof supposes; that *the Earth itself being in all its parts Magnetical, and the Water not; wheresoever the Land is, thither also should the Needle turn, as to the greater quantity of Magnetical Matter.* But this in many instances is not true; but most remarkably upon the Coast of *Brasile*, where the Needle is so far from being attracted by the Land, that it turns the quite contrary way, leaving the Meridian to lye N B E, which is just along the Coast. As to the Position of *Des Cartes*, *that the Iron and Loadstones hid in the Bowels of the Earth and the Bottom of the Sea may be the Causes that the Needle varies*; if we consider for how great a part of the Earths Surface, *ex gr.* in the whole *Indian* Sea, the Needle declines the same way, and that regularly, 'Twill follow that the attracting Substance that occasions it, must be very far distant. Now by Experience we find the little force that Iron Guns have upon the Compass in Ships (their Vertue, tho' they be demiculverin, or greater Cannon, being not perceptible at four or five Yards distance) and

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the Experiments now before the *Royal Society* do plainly shew, how little a Magnetism there is in most crude Iron Ores: What quantity thereof must be then suppos'd to make so powerful a Diversion at two or three Thousand Miles distance? Yet I cannot deny that in some places near the Shoar, or in Shoal-Water, the Needle may be irregularly directed from the aforesaid Causes, and that not a little, as *Gassendus* gives a notable instance of the Island *Elba* in the Mediterranean Sea: But these differences from the general Direction are always signs of the nearness of those Magnetical Substances, for the Production whereof that Island *Elba* has been famous from all Antiquity. Besides, against both *Des Cartes* and *Gilbert*, the change of the variation which has been within these Hundred Years last past more than 15 gr. at *London*, is an entire Demonstration; tho' *Des Cartes* does not stick to say, that the transportation of Iron from place to place, and the growth of new Iron within the Earth, where there was none before, may be the cause thereof. The same holds likewise against the *Hypothesis* of *Magnetical Fibres*, which *Kircher* maintains.

Now to propose something that may answer the several appearances, and introduce nothing strange in Philosophy, after a great many close Thoughts, I can come to no other Conclusion than that, *The whole Globe of the Earth is one great Magnet, having four Magnetical Poles, or Points of Attraction, near each Pole of the Equator Two; and that, in those parts of the World which lye near adjacent to any one of those Magnetical Poles, the Needle is governed thereby, the nearest Pole being always predominant over the more remote.* The parts of the Earth wherein these

Magnetical *Poles* lie, cannot as yet be exactly determin'd for want of sufficient *Data* to proceed Geometrically; but, as near as Conjecture can reach, I reckon that the *Pole*, which is at present neareſt to us, lies in or near the Meridian of the Lands end of *England*, and not above ſeven Degrees from the Pole Arctick, by this *Pole* the variations in all *Europe* and *Tartary*, and the *North Sea* are principally govern'd, tho' with regard to the other Northern Pole, whoſe ſituation is in a *Meridian* paſſing about the middle of *California*, and about 15 gr. from the North Pole of the World; to this the Needle has chiefly reſpect in all the North *America*, and in the two Oceans on either ſide thereof, from the *Azores* Weſtward to *Japan*, and farther. The two Southern Poles are rather farther diſtant from the South Pole of the World: The one about ſixteen Degrees therefrom, is in a Meridian, ſome twenty Degrees to the Weſtward of *Magellan Straights*, or ninty five Degrees Weſt from *London*: This commands the Needle in all the *South-America*, in the *Pacifick Sea*, and the greateſt part of the *Ethiopick* Ocean. The Fourth and laſt *Pole* ſeems to have the greateſt Power and largeſt Dominions of all, as it is the moſt remote from the Pole of the World, being little leſs than 20 Degrees diſtant there-from in the Meridian, which paſſes through *Hollandia Nova* and the Iſland *Celebes* about one hundred and twenty Degrees Eaſt from *London*; this Pole is predominant in the South part of *Africa*, in *Arabia* and the *Red Sea*, in *Perſia*, *India*, and its Iſlands, and all over the *Indian Sea*, from the Cape of *Good-Hope* Eaſtwards to the middle of the great South Sea that divides *Aſia* from *America*. This

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ſeems to be the preſent Diſpoſition of the Magnetical Vertue throughout the whole Globe of the Earth; it remains to ſhew how this Hypotheſis makes out all the variations that have been obſerv'd of late; and how it anſwers to our ſeveral Remarks drawn from the Table. And firſt it is plain, that (our *European* North *Pole* being in the Meridian of the Lands end of *England*) all places more Eaſterly than that will have it on the Weſt ſide of their Meridian, and conſequently the Needle, reſpecting it with its Northern Point, will have a Weſterly variation, which will ſtill be greater as you go to the Eaſtwards, till you come to ſome Meridian of *Ruſſia* where 'twill be greateſt, and from thence decreaſe again. Thus at *Breſt* the variation is but $1\frac{3}{4}$ Degrees, at *London* $4\frac{1}{2}$ Degrees; but at *Dantzick* ſeven Degrees Weſt. To the Weſtward of the Meridian of the Lands end, the Needle ought to have an Eaſterly variation; were it not that (by approaching the *American* Northern Pole, which lies on the Weſt ſide of the Meridian, and ſeems to be of greater force than this other) the Needle is drawn thereby Weſtwards, ſo as to counterballance the direction given by the *European Pole*, and to make a ſmall Weſt variation in the Meridian of the Lands end itſelf. Yet I ſuppoſe that about the Meridian of the Iſle *Tercera*, our neareſt Pole may ſo far prevail as to give the Needle a little turn to the Eaſt, tho' but for a very ſmall ſpace: The Counterballance of thoſe two Poles permitting no conſiderable variation in all the Eaſtern Parts of the *Atlantick* Ocean; nor upon the Weſt Coaſts of *England* and *Ireland*, *France*, *Spain* and *Barbary*. But to the Weſtwards of the *Azores* the Power of the *American*



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Pole overcoming that of the *European* the Needle has chiefly respect thereto, and turns still more and more towards it as you approach it. Whence it comes to pass, that on the Coast of *Virginia*, *New-England*, *New-found-Land*, and in *Hudson*'s-*Straights* the variation is Westward; that it decreases as you go from thence towards *Europe*, and that it is less in *Virginia* and *New-England*, than in *New-found-Land*, and *Hudson*'s-*Straights*. This Westerly variation again decreases, as you pass over the *North America*; and about the Meridian of the middle of *California* the Needle again points due North; and from thence Westward to *Tedzo* and *Japan*, I make no doubt but the variation is Easterly, and half the Sea over no less than fifteen Degrees, if there be any truth in this Hypothesis of mine. Therefore I propose this as a trial, that the whole may be scann'd thereby; and I conceive it will not be hard to know of the *Spaniards* how it is, who so frequently sail through that Ocean, in their return from the *Manilha* Isles. This East variation extends over *Japan*, *Tedzo*, *East-Tartary*, and part of *China*, till it meet with the Westerly, which is govern'd by the *European* North Pole, and which I said was greatest somewhereIn *Russia*.

Towards the Southern Pole the effect is much the same, only that here the South Point of the Needle is attracted. Hence it will follow, that the variation on the Coast of *Brazile*, at the River of *Plate*, and so on to the Straits of *Magellan* should be Easterly (as in our third Remark); if we suppose a Magnetical Pole situate about twenty Degrees more Westerly than the Straights of *Magellan*. And this Easterly variation doth extend Eastward over the greatest

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part of the *Ethiopick* Sea, till it be counterpoised by the Vertue of the other Southern *Pole*; as it is about mid-way between the Cape of *Good-Hope*, and the Isles of *Tristan d' Acuntia*. From thence Eastwards, the *Asian* South Pole (as I must take the liberty to call it) becoming prevalent, and the South point of the Needle being attracted thereby, there arises a West variation very great in quantity and extent, because of the great distance of this Magnetical Pole of the World. Hence it is, that in all the *Indian* Sea as far as *Hollandia Nova*, and farther, there is constantly West variation; at that under the Equator itself it arises to no less than eighteen Degrees, where 'tis most. About the Meridian of the Island *Celebes*, being likewise that of this Pole, this Westerly variation ceases, and an Easterly begins; which reaches, according to my Hypothesis, to the middle of the *South-Sea* between *Zelandia Nova* and *Chili*, leaving room for a small *West Variation* govern'd by the *American* South Pole, which I shew'd to be in the *Pacifick Sea*, in the sixth and seventh Remark.

What I have now said, does plainly shew the sufficiency of this Hypothesis for solving the variations that are at this time observ'd in the temperate and frigid *Zones*, where the direction of the Needle chiefly depends upon the Counterpoise of the forces of two Magnetical Poles of the same Nature; and I suppose I have shewn how it comes to pass, that under the same Meridian the variation should be in one place 29½ West, and another 20½ East; as I have noted in my ninth Remark.

In the *Torrid Zone*, and particularly under the Equinoctial, respect must be had to all four

Poles, and their Positions well consider'd, otherwise it will not be easie to determine what the variations shall be; the neareſt Pole being always the ſtrongeſt; yet not ſo, as not to be counterballanc'd ſometimes by the united forces of two more remote, a notable Inſtance whereof is in our eighth Remark, where I took notice, that in ſailing from St. *Helena* by the Iſle of *Aſcenſion*, to the Equator, on a *NW.* Courſe the variation is very little Eaſterly, and in that whole Tract unalterable; for which I give this Reaſon, that the South *American* Pole (which is conſiderably the neareſt in the aforeſaid places) requiring a great Eaſterly variation is counterpoiſed by the contrary Attraction of the *North-American* and the *Aſian-South* Pole; each whereof ſingly are in theſe parts, weaker than the *American-South-Pole*; and upon the *NW.* Courſe, the diſtance from this latter is very little varied; and as you recede from the *Aſian-South-Pole*, the ballance is ſtill preſerv'd by the acceſs towards the *North-American-Pole*. I mention not in this caſe the *European North-Pole*, its Meridian being little remov'd from thoſe of theſe places; (and of it ſelf requiring the ſame variations we here find. After the ſame manner we might proceed to conclude the variations in other places under and near the Equator; but I purpoſely leave it for an exerciſe to the Thoughts of the ſerious Reader, who is deſir'd to help his Imagination, by having before him a Map or Globe of the Earth: And to mark thereon the Magnetical Poles in the *Longitudes* and *Latitudes* I aſſign them. (*Vide Plat.* 2.)

Thus

Thus, I hope, I have not lost my Pains and Study in this difficult Subject; believing that I have put it past doubt, *That there are in the Earth four such Magnetical Points or Poles which occasion the great variety and seeming irregularity which is observ'd in the variations of the Compass.* But to calculate exactly what it is, in any place assign'd, is what I dare not yet pretend to, tho' I could wish it were my happiness to be able to oblige the World with so useful a piece of Knowledge; there are difficulties that occur, that render the thing as yet not feasible, for first there are a great many Observations requisite, which ought to be made at the same time; not at Sea, but ashore, with greater Care and Attention than the generality of Sailors apply. And besides it remains undetermin'd in what proportion the attractive Power decreases, as you remove from the Pole of a Magnet, without which it were a vain attempt to go about to calculate. There is yet a further difficulty, which is the change of the variation, one of the discoveries of this last Century; which shews, that it will require some hundreds of Years to establish a compleat Doctrine of the Magnetical System. From the foregoing Table it should seem, that all the Magnetical Poles had a motion Westward: But if it be so, 'tis evident, that it is not a Rotation about the Axis of the Earth; for then the variations would continue the same, in the same parallel of *Latitude* (the *Longitude* only changed) as much as is the motion of the Magnetical Poles, but the contrary is found by Experience; for there is no where in the Latitude of $15\frac{1}{2}$ North between *England* and *America*, a variation of eleven Degrees East at this time; as

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as it was once here at *London*; it seems therefore, that our *European* Pole is grown nearer the Pole *Arctick* than it was heretofore, or else that it has lost part of its Vertue. But whether these Magnetical Poles move altogether with one motion, or with several; whether equally or unequally; whether Circular or Libratory: If Circular, about what Center; if Libratory, after what manner; are Secrets as yet utterly unkown to Mankind, and are reserv'd for the Industry of future Ages.



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## *An Account of the Cause of the Change of the Variation of the Magnetical Needle, with an Hypothesis of the Structure of the Internal parts of the Earth; as it was proposed to the* Royal Society *in one of their late Meetings. By Mr.* Edmund Halley.

HAving in the precedent Discourse delivered a Theory of the Variation of the Magnetical Compass, wherein I did collect as many Observations as at that time I could procure, and having carefully compar'd them together, I came at length to this general conclusion, *That the Globe of the Earth might be supposed to be one great Magnet, having four Magnetical Poles or Points of Attraction, near each Pole of the Equator two; and that in those parts of the World which lie near adjacent to any one of those Magnetical Poles, the Needle is chiefly govern'd thereby; the nearest Pole being always predominant over the more remote.* And I there have endeavour'd to state and limit the present Position of those Poles in the Surface of our Globe, which the Reader pleasing to consult will save us the pains of repeating. But after all, tho' that Discourse was favourably receiv'd both at home and abroad, as seeming to render a tolerable account of the observ'd variations

variations, yet I found two difficulties not easie to surmount, the one was, that no Magnet I had ever seen or heard of, had more than two opposite Poles, whereas the Earth had visibly four, and perhaps more. And secondly, it was plain that these Poles were not, at least all of them, fixt in the Earth, but shifted from place to place, as appear'd by the great changes in the Needles direction within this last Century of Years, not only at *London*, (where this great Discovery was first made) but almost all over the Globe of Earth; whereas it is not known or observ'd that the Poles of a Load-stone ever shifted their place in the Stone, nor (considering the compact hardness of that substance) can it easily be suppos'd; tho' the matter of Fact be too notorious and universal, not to be accounted for.

These difficulties had wholly made me despond, and I had long since given over an Inquiry I had so little hopes of, when in accidental Discourse, and least expecting it, I stumbl'd on the following Hypothesis; in delivering whereof, if I shall seem to advance any thing that looks like Extravagant or Romantick, the Reader is desir'd to suspend his Censure, till he have consider'd the force and number of the many Arguments which concur to make good so new and so bold a Supposition.

Tho' it be sufficiently known and allow'd, that the Needles variation changes, it will be necessary however to give a few instances, whereby it may appear that this change is gradual and universal, and the effect of a great and permanent motion: For which take the following Examples.

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At *London*, in the Year 1580, the variation was observ'd by Mr. *Burrows* to be 11°. 15′ East. In *Anno* 1622, the same was found by Mr. *Gunter* to be but 6° 0′ East. In the Year 1634, Mr. *Gellibrand* found it 4°. 5′ East. In 1657, Mr. *Bond* observ'd that there was no variation at *London*. *Anno* 1672, my self observ'd it 2°. 30′ to the West; and in the Year 1692, I again found it 6° 00′ West. So that in 112 Years the direction of the Needle has chang'd no less than seventeen Degrees.

At *Paris*. *Orontius Finæus* about the Year 1550, did account it about eight or nine Degrees East variation. *Anno*. 1640, it was found three Degrees East. *Anno* 1666, there was no variation there, and *Anno* 1681, I found it to be 2°. 30′ to the West.

At *Cap. d' Agulhas*, the most Southerly Promontary of *Africa*, about the Year 1600, the Needle pointed due North and South without variation, whence the *Portugueze* gave its name. *Anno* 1622, there was two Degrees West variation. *Anno* 1675, it was 8°. 00 West; and in the Year 1691, it was curiously observ'd not less than eleven Degrees West.

At St. *Helena*, about the Year 1600, the Needle declin'd eight Degrees to the East. *Anno* 1623, it was but 6°. 00′ East. *Anno* 1677, when I was there, I observ'd it accurately on Shoar to be 0*d*. 40′ East; and in 1692 it was found about 1 *d*. to the Westward of the North.

At *Cape Comorine* in *India*, in the Year 1620, there was 14 gr. 20′ West variation. In the Year 1680, there was 8°. 48′, but now lately in the Year 1688, it was no more than 7°. 30′, so that here the Needle has return'd to the East about seven Degrees in seventy Years. In

In all the other Examples the Needle has gradually mov'd towards the West, and the places are too far asunder, to be influenc'd by the removal of any Magnetical Matter, which may by accident be transplac'd within the Bowels, or on the Surface of the Earth. If more Examples are desir'd, the Reader may be furnish'd with them in the *Portugueze Routier* of *Aleixo de Motta* (written about the Year 1600) and in the Voyage of *Beaulieu*, both publish'd in Mr. *Thevenot*'s first Collection of curious Voyages, Printed at *Paris*, *Anno* 1663; which he is to compare with the Journals of our late *East India* Voyagers, and I am assur'd, that it will be thereby evident, that the direction of the Needle is in no place fix'd and constant, tho' in some it change faster than in others: And where for a long time it has continu'd as it were unalter'd, it is there to be understood, that the Needle has its greatest Deflection, and is become Stationary in order to return, like the Sun, in the Tropick. This, at present, is in the *Indian Sea*, about the Island *Mauritius*, where is the highest West variation, and in a Tract tending from thence into the N. N. W. towards the *Red-Sea* and *Egypt*. And in all Places to the Westward of this Tract, all over *Africa* and the Seas adjoining, the West variation will be found to have encreas'd; and to the Eastwards thereof, as in the Example of *Cape Comorin*, to have decreas'd, *viz.* all over the *East-Indies* and the Islands near it.

After the like manner in that Space of East variation, which, beginning near St. *Helena*, is found all over the South *America*, and which at present is highest about the Mouth of *Rio de la Plata*, it has been observ'd, that in the Eastern Parts

Parts thereof, the variation of the Needle gradually decreases; but whether on the contrary it increases in those places which lie more Westerly than that Tract wherein the highest East variation is found; or how it may be in the vast *Pacifick-Sea*, we have not Experience enough to ascertain, only we may by Analogy infer, that both the East and West variations therein do gradually increase and decrease after the same Rule.

These *Phænomena* being well understood and duly consider'd, do sufficiently evince, That the whole Magnetical System is by one, or perhaps more motions translated, whether Eastwards or Westwards, I shall anon discuss; that this moving thing is very great, as extending its effects from Pole to Pole; and that the motion thereof it not *per saltum*, but a gradual and regular motion.

Now considering the Structure of our *Terraqueous* Globe, it cannot be well suppos'd that a very great part thereof can move within it, without notably changing its Center of Gravity and the Equilibre of its Parts, which would produce very wonderful Effects in changing the Axis of diurnal Rotation, and occasion strange alteration in the Seas Surface, by Inundations and Recesses thereof, such as History never yet mention'd. Besides, the solid parts of the Earth are not to be granted permeable by any other than fluid Substances, of which we know none that are any ways Magnetical. So that the only way to render this motion intelligible and possible, is, to suppose it to turn about the Center of the Globe, having its Center of Gravity fix'd and immoveable in the same common Center of the Earth: And there is yet requir'd,

that

that this moving internal Substance be loose and detached from the external Parts of the Earth whereon we live; for otherwise were it affix'd thereto, the whole must necessarily move together.

So then the External Parts of the Globe may well be reckon'd as the Shell, and the Internal as a *Nucleus* or inner Globe included within ours, with a fluid medium between, which having the same common Center and Axis of diurnal Rotation, may turn about with our Earth each twenty four Hours; only this outer Sphere having its turbinating motion some small matter either swifter or slower than the internal Ball: And a very Minute difference in length of time, by many repetitions becoming sensible, the Internal Parts will by degrees recede from the External, and not keeping pace with one another will appear gradually to move either Eastwards or Westwards by the difference of their motions.

Now supposing such an Internal Sphere having such a motion, we shall solve the two great Difficulties we encounter'd in my former Hypothesis: For if this exterior Shell of Earth be a Magnet having its Poles at a distance from the Poles of diurnal Rotation; and if the Internal *Nucleus* be likewise a Magnet, having its Poles in two other places distant also from the Axis; and these latter by a gradual and slow motion change their place in respect of the External; we may then give a reasonable account of the four Magnetical Poles I presume to have demonstrated before; as likewise of the changes of the Needles variations, which till now hath been unattempted.

The

The Period of this motion being wonderful great, and there being hardly an hundred Years since these Variations have been duly observ'd, it will be very hard to bring this Hypothesis to a Calculus, especially since, tho' the Variations do increase and decrease regularly in the same place, yet in differing places, at no great distance, there are found such casual Changes thereof as can no ways be accounted for by a regular Hypothesis; as depending upon the unequal and irregular distribution of the Magnetical Matter within the substance of the external Shell or Coat of the Earth, which deflect the Needle from the Position it would acquire from the effect of the general Magnetism of the whole. Of this the Variations at *London* and *Paris* give a notable instance, for the Needle has been constantly about $1^{o}\frac{1}{2}$ more Easterly at *Paris* than at *London*; tho' it be certain that according to the general effect, the difference ought to be the contrary way: Notwithstanding which the Variations in both places do change alike.

Hence, and from some other of like Nature, I conclude, That the two Poles of the external Globe are fixt in the Earth, and that if the Needle were wholly govern'd by them, the Variations thereof would be always the same, with some little Irregularities upon the account I but just now mention'd: But the internal Sphere having such a gradual translation of its Poles, does influence the Needle, and direct it variously according to the result of the attractive or directive Power of each Pole; and consequently there must be a Period of the Revolution of this internal Ball, after which the Variations will return again as before. But if it

shall in future Ages be observ'd otherwise, we must then conclude that there are more of these Internal Spheres, and more Magnetical Poles than Four, which at present we have not a sufficient number of Observations to determine, and particularly in that vast *Mar del Zur*, which occupies so great a part of the whole Surface of the Earth.

If then two of the Poles be fixt and two moveable, it remains to ascertain which they are that keep their place; and tho' I could wish we had the experience of another Century of Years to found our Conclusions upon, yet I think we may safely determine, *That our European North Pole* (which in the precedent Discourse I suppos'd near the Meridian of the Lands end of *England*, and about 7 Degrees therefrom) is that That is moveable of the two Northern Poles, and that That has chiefly influenc'd the Variations in these parts of the World; For in *Hudson*'s Bay, which is under the Direction of the *American* Pole, the change is not observ'd to be near so fast as in these parts of *Europe*, tho' that Pole be much farther remov'd from the Axis.

As to the *South Poles*, I take the *Asian* Pole, which I place about the Meridian of the Island *Celebes* to be the fixt, and consequently the *American* Pole to move; from the like Observation of the slow Decrease of the Variation on the Coast of *Java*, and near the Meridian of the *Asian* Pole; tho' I must confess to have no account of the effects of the other beyond *Magellan*'s Streights.

If this be allow'd me, 'tis plain that the fixt Poles are the Poles of this External Shell or Cortex of the *Earth*, and the other two the Poles of a Magnetical *Nucleus* included and moveable

moveable within the other. It likewise follows, that this Motion is Westwards, and by consequence that the aforesaid *Nucleus* has not precisely attained the same degree of Velocity with the exteriour Parts in their diurnal Revolution; but so very nearly equals it, that in 365 Revolves the difference is scarce sensible. This I conceive to arise from the Impulse whereby this diurnal Motion was impress on the Earth, being given to the external Parts, and from thence in time communicated to the Internal; but not so as perfectly to equal the Velocity of the first Motion impress'd on, and still conserv'd by the superficial Parts of the Globe.

As to the Quantity of this Motion it is almost impossible to define it, both from the Nature of this kind of Observation, which cannot be very accurately perform'd, as also from the small time these Variations have been observ'd, and their change discover'd. It appears by all Circumstances, that its Period is of many Centuries of Years, and as far as may be collected from the Change of the Place, where there was no Variation by reason of the Equilibre of the two Southern Magnetical Poles, *viz.* from *Cape d' Agulhas* to the Meridian of St. *Helena* (which is about 23gr in about ninty Years) and of the place where the Westerly Variation is in its ἀκμὴ or greatest Deflection, being about half so much, *viz.* from the Isle of *Diego Roiz* to the South West Parts of *Madagascar*. We may with some Reason conjecture, that the *American* Pole has mov'd Westwards fourty six Degrees in that time, and that the whole Period thereof is perform'd in seven hundred Years, or thereabouts; so that the nice Determination of this and of several other particulars in the



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Magnetick System is reserv'd for remote Posterity; all that we can hope to do, is to leave behind us Observations that may be confided in, and to propose Hypothesis which after Ages may examine, amend or refute. Only here I must take leave to recommend to all Masters of Ships and all others, Lovers of Natural Truths, that they use their utmost Diligence to make, or procure to be made, Observations of these Variations in all parts of the World, as well in the North as South Latitude (after the laudable Custom of our *East-India* Commanders) and that they please to communicate them to the *Royal Society*, in order to leave as compleat a History as may be to those that are hereafter to compare all together, and to compleat and perfect this abstruse Theory.

And by the way it will not be amiss to amend a receiv'd Error in the Practice of observing the Variation, which is, to take it by the Amplitude of the Rising and Setting Sun, when his Center appears in the visible Horizon; whereas he ought to be observ'd when his under Limb is still above the Horizon about $\frac{3}{4}$ of his Diameter, or twenty Minutes, upon the score of the Refraction, and the height of the Eye of the Observer above the Surface of the Sea: Or else they are to work the Amplitudes as they do the Azimuth, reckoning the Suns distance from the Zenith 90°. 36′: This, tho' it be of little consequence near the Equinoctial, will make a great error in high Latitudes, where the Sun rises and sets obliquely.

But to return to our Hypothesis, In order to explain the change of the Variations, we have adventur'd to make the Earth hollow and to place

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place another Globe within it; and I doubt not but this will find Opposers enough. I know 'twill be Objected, That there is no Instance in Nature of the like thing; that if there was such a middle Globe it would not keep its place in the Centre, but be apt to deviate there-from, and might possibly chock against the Concave Shell, to the ruine, or at least endammaging thereof; That the Water of the Sea would perpetually leak through, unless we suppose the Cavity full of Water; That were it possible, yet it does not appear of what use such an inward Sphere can be of, being shut up in eternal Darkness, and therefore unfit for the Production of Animals or Plants; with many more Objections, according to the Fate of all such new Propositions.

To these, and all other that I can foresee, I briefly Answer, That the Ring environing the Globe of *Saturn* is a notable Instance of this kind, as having the same common Center, and moving along with the Planet, without sensibly approaching him on one side more than the other. And if this Ring were turn'd on one of its Diameters, it would then describe such a Concave Sphere as I suppose our External one to be. And since the Ring, in any Position given, would, in the same manner, keep the Centre of *Saturn* in its own, it follows, that such a Concave Sphere may move with another included in it, having the same common Centre. Nor can it well be suppos'd otherwise, considering the Nature of Gravity; for should these Globes be adjusted once to the same common Centre, the Gravity of the parts of the Concave would press equally towards the Centre of the inner Ball, which equality must necessarily

ſarily continue till ſome external Force diſturb it, which is not eaſie to imagine in our caſe. This perhaps I might more intelligibly expreſs, by ſaying that the inner Globe being poſited in the Centre of the Exterior, muſt neceſſarily aſcend which way ſoever it move; that is, it muſt overcome the force of Gravity preſſing towards the common Centre, by an impulſe it muſt receive from ſome outward Agent; but all outward Efforts being ſufficiently fenc'd againſt by the Shell that ſurrounds it, it follows, that this *Nucleus* being once fixt in the common Centre, muſt alwas there remain.

As to the leaking of the Water through this Shell, when once a paſſage ſhall be found for it to run through, I muſt confeſs it is an Objection ſeemingly of weight; but when we conſider how tightly great Beds of Chalk or Clay, and much more Stone do hold Water, and even Caves arch'd with Sand; no Man can doubt but the Wiſdom of the Creator has provided for the Macrocoſm by many more ways than I can either imagine or expreſs, eſpecially ſince we ſee the admirable and innumerable Contrivances wherewith each worthleſs Individual is furniſh'd both to defend itſelf and propagate its Species. What Curioſity in the Structure, what Accuracy in the Mixture and Compoſition of the parts ought not we to expect in the Fabrick of this Globe, made to be the laſting Habitation of ſo many various Species of Animals, in each of which there want not many Inſtances that manifeſt the boundleſs Power and Goodneſs of their Divine Author; and can we then think it a hard ſuppoſition that the Internal Parts of this Bubble of Earth ſhould be replete with ſuch Saline and Vitriolick Particles as may contribute

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tribute to Petrifaction, and dispose the transuding Water to shoot and coagulate into Stone, so as continually to fortifie, and, if need were, to consolidate any breach or flaw in the Concave surface of the Shell.

And this perhaps may not without reason be suppos'd to be the final Cause of the admixture of the Magnetical Matter in the Mass of the Terrestial parts of our Globe, *viz.* To make good and maintain the Concave Arch of this Shell: For by what the excellent Mr. *Newton* has shewn in his *Principia Philosophiæ*, it will follow, that according to the general Principle of Gravity, visible throughout the whole Universe, all those Particles that by length of time or otherwise, shall moulder away or become loose on the Concave Surface of the External Sphere, would fall in, and with great force descend on the Internal, unless those Particles were of another sort of Matter capable by their stronger tendency to each other, to suspend the force of Gravity; but we know no other Substances capable of supporting each other by their mutual Attraction but the Magnetical, and these we see miraculously to perform that Office, even where the Power of Gravity has its full effect, much more within the Globe where it is weaker. Why then may we not suppose these said Arches to be lin'd throughout with a Magnetical Matter, or rather to be one great Concave Magnet, whose two Poles are the Poles we have before observ'd to be fixt in the Surface of our Globe.

Another Argument, favouring this Hypothesis, is drawn from a Proposition of the same Mr. *Newton*, where he determines the force wherewith the *Moon* moves the *Sea* in produc-

ing the *Tides*: His words are, *Densitas Lunæ est ad densitatem Terræ ut* 680 *ad* 387 *seu* 9 *ad* 5 *quamproximè. Est igitur corpus Lunæ densius ac magis terestre quam Terra nostra*, p. 466. Now if the Moon be more solid than the Earth, as 9 to 5, why may we not reasonably suppose the Moon, being a small Body and a Secondary Planet, to be solid Earth, Water, Stone, and this Globe to consist of the same Materials, only four Ninths thereof to be Cavity, within and between the internal Spheres; which I would render not improbable.

To those that shall enquire of what use these included Globes can be, it must be allow'd, that they can be of very little service to the Inhabitants of this outward World, nor can the Sun be serviceable to them, either with his Light or Heat. But since it is now taken for granted, that the Earth is one of the Planets, and they all are with reason suppos'd Habitable, though we are not able to define by what sort of Animals; and since we see all the parts of the Creation abound with Animate Beings, as the Air with Birds and Flies, the Water with the numerous varieties of Fish, and the very Earth with Reptiles of so many sorts; all whose ways of Living would be to us incredible did not daily Experience teach us. Why then should we think it strange that the prodigious Mass of Matter, whereof this Globe does consist, should be capable of some other improvement than barely to serve to support its Surface? Why may not we rather suppose that the exceeding small quantity of solid Matter in respect of the fluid Æther, is so dispos'd by the Almighty Wisdom, as to yield as great a Surface for the use of living Creatures, as can consist

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sist with the conveniency and security of the whole? We our selves, in Cities where we are pressed for room, commonly build many Stories one over the other, and thereby accommodate a much greater multitude of Inhabitants.

But still it will be said, that without Light there can be no living, and therefore all this *apparatus* of our inward Globes must be useless: To this I Answer, That there are many ways of producing Light which we are wholly ignorant of; the Medium itself may be always luminous after the manner of our *Ignes fatui*. The Concave Arches may in several places shine with such a Substance as invests the Surface of the Sun; nor can we, without a boldness unbecoming a Philosopher, adventure to assert the impossibility of peculiar Luminaries below, of which we have no sort of *Idea*. I am sure the Poets *Virgil* and *Claudian* have gone before me in this Thought, inlightning their *Elysian Fields* with Sun and Stars proper to those infernal, or rather internal, Regions. *Virg. Æneid. 6.*

*Largior hic campos Æther & lumine vestit.*
*Purpureo; Solemque suum sua Sidera norunt.*

And *Claudian* lib. 2. *De Raptu Proserpinæ.*

*Amissum ne crede diem, sunt altera nobis*
*Sidera, sunt orbes alii, lumenque videbis*
*Purius, Elysiumque magis mirabere Solem.*

And tho' this be not to be esteem'd as an Argument, yet I may take the liberty I see others do, to quote the Poets when it makes for my purpose.

Lastly,

Lastly, To explain yet farther what I mean, I have adventur'd to adjoin the following Scheme, (*Table* 1. *Fig.* 3.) wherein the Earth is represented by the outward Circle, and the three inward Circles are made nearly proportionable to the Magnitudes of the Planets *Venus*, *Mars* and *Mercury*, all which may be included within the Globe of Earth, and all the Arches more than sufficiently strong to bear their weight. The Contave of each Arch, which is shaded differently from the rest, I suppose to be made up of Magnetical Matter; and the whole to turn about the same common Axis *p*, *p*, only with this difference, that the Outer Sphere still moves somewhat faster than the Inner. Thus the Diameter of the Earth being about eight thousand *English* Miles, I allow five hundred Miles for the thickness of its Shell, and another space of five hundred Miles for a Medium between, capable of an immense Atmosphere for the use of the Globe of *Venus*: *Venus* again I give a Shell of the same thickness, and leave as great a space between her Concave and *Mars*; so likewise from *Mars* to *Mercury*, which latter Ball we will suppose solid, and about two thousand Miles Diameter. Thus I have shew'd a possibility of a much more ample Creation, than has hitherto been imagin'd; and if this seem strange to those that are unacquainted with the Magnetical System, it is hop'd that all such will endeavour, first, to inform themselves of the Matter of Fact, and then try if they can find out a more simple Hypothesis, at least a less absurd, even in their own Opinions. And whereas I have adventur'd to make these Subterraneous Orbs capable of being Inhabited, 'twas done designedly for the sake of those who will be apt

to

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to ask *cui bono*, and with whom Arguments drawn from *Final Cauſes* prevail much. If this ſhort Eſſay ſhall find a kind acceptance, I ſhall be encourag'd to enquire farther, and to Poliſh this rough Draft of a Notion till hitherto not ſo much as ſtarted in the World, and of which we could have no Intimation from any other of the *Phænomena* of Nature.

Since this was written, a Diſcovery I have made in the Celeſtial Motions, ſeems to render a farther account of the Uſe of the Cavity of the Earth, *viz.*, To diminiſh the Specifick Gravity thereof in reſpect of the Moon; for I think I can demonſtrate that the Oppoſition of the Æther to the Motions of the Planets in long time becomes ſenſible; and conſequently the greater Body muſt receive a leſs Oppoſition than the ſmaller, unleſs the Specifick Gravity of the ſmaller do proportionably exceed that of the greater, in which caſe only they can move together; ſo that the Cavity I aſſign in the Earth, may well ſerve to adjuſt its weight to that of the Moon; for otherwiſe the Earth would leave the Moon behind it, and ſhe become another Primary Planet.

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## *An Historical Account of the* Trade Winds *and* Monsoons, *observable in the Seas between and near the* Tropicks, *with an attempt to assign the Physical Cause of the said Winds, by Mr.* Ed. Halley.

AN exact Relation of the constant and Periodical Winds, observable in several Tracts of the Ocean, is a part of Natural History not less desireable and useful, than it is difficult to obtain, and its *Phenomena* hard to explicate: I am not ignorant that several Writers have undertaken this Subject, and altho' *Varenius* (*Lib.* 1. *Chap.* 21. *Gen. Gth.*) seems to have endeavour'd after the best information from *Voyagers*, yet cannot his accounts be admitted for accurate, by those that shall attentively consider and compare them together, and some of them are most evident mistakes; which, as near as I can, I shall attempt to rectify, having had the opportunity of conversing with Navigators acquainted with all parts of *India*, and having liv'd a considerable time between the *Tropicks*, and there made my own Remarks.

The Substance of what I have collected is briefly as follows.

The Universal *Ocean* may most properly be divided into three Parts, *viz.* 1. The *Atlantick* and *Æthiopick-Sea*. 2. The The *Indian Ocean*. 3. The

3. The Great *South Sea*, or the *Pacifick Ocean*; and tho' these Seas do all communicate by the South, yet as to our present purpose of the *Trade Winds*, they are sufficiently seperated by the interposition of great Tracts of *Land*; the first lying between *Africa* and *America*, the second between *Africa*, and the *Indian Islands* and *Hollandia Nova*; and the last between the *Philippine Isles*, *China*, *Japan* and *Hollandia Nova* on the *West*, and the Coast of *America* on the *East*. Now following this natural division of the Seas, so will we divide our History into three parts in the same order.

1. In the *Atlantick* and *Æthiopick* Seas between the *Tropicks*, there is a general *Easterly Wind*, all the Year long, without any considerable Variation, excepting that it is subject to be deflected hence from, some few Points of the Compass towards the *North* or *South*, according to the Position of the place. The Observations which have been made of these Deflections, are the following.

That near the Coast of *Africa*, as soon as you have past the *Canary Isles* you are sure to meet a fresh Gale on *N. E.* Wind about the Latitude of 28 Degrees *North*, which seldom comes to the *Eastwards* of the *E. N. E.* or passes the *N. N. E.* This Wind accompanies those bound to the Southward, to the Latitude of 10 North, and about a hundred Leagues from the *Guinea* Coast, where, till the fourth Degree of North Latitude, they fall into the Calmes and Tornadoes, of which more hereafter.

2. That

2. That those bound to the *Caribbe Isles*, find, as they approach the *American* side, that the afore-said North-East Wind, becomes still more and more Easterly, so as sometimes to be East, sometimes East by South, but yet most commonly to the Northward of the East a Point or two, seldom more. 'Tis likewise observ'd, that the strength of these Winds does gradually decrease, as you sail to the Westwards.

3. That the limits of the Trade and variable Winds, in this Ocean, are farther extended on the *American* side than the *African*; for whereas you meet not with this certain Wind till after you have pass'd the Latitude of twenty eight degrees on this side; on the *American* side it commonly holds to thirty, thirty one, or thirty two degrees of Latitude; and this is verified likewise to the Southwards of the Æquinoctial, for near the *Cape* of *Good-Hope* the limits of the Trade Winds, are three or four Degrees nearer the Line, than on the Coast of *Brazile*.

4. That from the Latitude of four Degrees North, to the afore-said Limits on the South of the Æquator, the Winds are generally and perpetually between the South and East, and most commonly between the South-East and East, observing always this Rule, that on the *African* side they are more Southerly, on the *Brasilian* more Easterly, so as to become almost due East, the little deflection they have being still to the Southwards. In this part of the Ocean it has been my fortune to pass a full Year, in an Employment that oblig'd me to regard more than ordinary the Weather, and I found the Winds constantly about the South-East, the most usual Point *SE b E*; when it

was

was Eaſterly it generally blew hard, and was gloomy, dark, and ſometimes rainy Weather; if it came to the Southwards it was generally Serene, and a ſmall Gale next to a Calm, but this not very common. But I never ſaw it to the Weſtwards of the South, or Northwards of the Eaſt.

5. That the Seaſon of the Year has ſome ſmall effect on theſe Trade Winds, for that when the Sun is conſiderable to the Northwards of the Æquator, the South-Eaſt Winds, eſpecially in the Straight of this Ocean (if I may ſo call it) between *Braſile* and the Coaſt of *Guinea*, do vary a Point or two to the Southwards, and the North-Eaſt become more Eaſterly; and on the contrary, when the Sun is towards the Tropick of *Capricorn* the South-Eaſterly Winds become more Eaſterly, and the North-Eaſterly Winds on this ſide the Line vere more to the Northwards.

6. That as there is no general Rule that admits not of ſome exception, ſo there is in this Ocean a Tract of Sea wherein the Southerly and South-Weſt Winds are perpetual, *viz.* all along the Coaſt of *Guinea*, for above five hundred Leagues together, from *Sierra Leona* to the Ile of St. *Thomas*; for the South-Eaſt Trade Wind having paſs'd the Line, and approaching the Coaſt of *Guinea* within eighty or 100 Leagues inclines towards the Shore and becomes S. S. E., and by Degrees, as you come nearer, it veres about to South, S. S. Weſt, and in with the Land South-Weſt, and ſometimes Weſt South-Weſt; which Variation is better expreſs'd in the Mapp hereto annexed, (*Vide Plan* 2.) than it can well be in words. Theſe are the Winds which are obſerv'd on this Coaſt when it blows

blows true, but there are frequent Calms, Violent suddain Gusts call'd *Tornado's*, from all Points of the Compass, and sometimes unwholsome foggy Easterly Winds call'd *Hermitaa* by the Natives, which too often infest the Navigation of these parts.

7. That to the Northwards of the Line, between four and ten Degrees of Latitude, and between the Meridians of *Cape Virde*, and of the Eastermost Islands that bear that Name, there is a Tract of Sea wherein it were improper to say there is any Trade Wind, or yet a Variable; for it seems condemn'd to perpetual Calms, attended with terrible Thunder and Lightning, and Rains so frequent, that our Navigators from thence call this part of the Sea the *Rains*; the little Winds that are, be only some suddain uncertain Gusts, of very little continuance and less extent; so that sometimes each hour you shall have a different Gale, which dies away into a Calm before another succeed, and in a Fleet of Ships in sight of one another, each shall have the Wind from a several Point of the Compass; with these weak *Brizes* Ships are oblig'd to make the best of their way to the Southward through the afore-said six Degrees, wherein 'tis reported some have been detain'd whole Months for want of Wind.

From the three last observables is shewn the Reason of two notable Occurents in the *East-India* and *Guinea* Navigations: The one is, why, notwithstanding the narrowest part of the Sea between *Guinea* and *Brasile* be about five hundred Leagues over, yet Ships bound to the Southward sometimes, especially in the Months of *July* and *August*, find a great difficulty to pass it. This happens because of the South-

East Winds, at that time of the Year commonly extending ſome Degrees beyond the ordinary limit of four Degrees North Latitude, and withal they come ſo much Southerly, as to be ſometimes South, ſometimes a Point or two to the Weſt; there remains then only to ply to Wind-ward, and if on the one ſide they ſtand away W. S. W. they gain the Wind ſtill more and more Eaſterly, but there is danger of not weathering the *Braſilian* Shore, or at leaſt the Shoals upon that Coaſt. But if upon the other Tack they go away E. S. E. they fall into the Neighbourhood of the Coaſt of *Guinea*, from which there is no departing without running Eaſterly, as far as the Iſle of St. *Thomas*, which is the conſtant practiſe of all the *Guiny* Ships, and which may ſeem very ſtrange without the conſideration of the ſixth Remark, which ſhews the reaſon of it: For being in with the Coaſt, the Wind blows generally at S. W. and W. S. W. with which Winds they cannot go to the Northward for the Land, and on the other Tack they can lie no nearer the Wind than S. S. E. or South; with theſe Courſes they run off the Shore, but in ſo doing they always find the Winds more and more contrary; ſo that when near the Shore they could lie South, at a greater diſtance they can make their way no better than S. E. and afterwards E. S. E. with which courſes they fetch commonly the Iſle of St. *Thomas* and Cape *Lopez*, where finding the Winds to the Eaſtward of the South, they keep them favourable by running away to the Weſtward in the South Latitude, of three or four Degrees, where the S. E. Winds are perpetual.

For the ſake of theſe general Winds, all thoſe

those that use the *West-Indian* Trade, even those bound to *Virginia*, count it their best course to get as soon as they can to the Southwards, that so they may be certain of a fair and fresh Gale to run before it to the Westwards; and for the same reason those homewards bound from *America*, endeavour to gain the Latitude of thirty Degrees, as soon as possible, where they first find the Winds begin to be Variable; though the most ordinary Winds in the Northern part of the *Atlantick* Ocean come from between the South and West.

As to those furious Storms call'd *Hurricanes*, which are, as it were, peculiar to the *Caribbe* Isles; and which so dreadfully afflict them in the Month of *August*, or not much before or after, they do not so properly belong to this place, both by reason of their small continuance and extent, as likewise because they are not Anniversary, some Years having more than one, and sometimes for several Years together there being none at all. But their Violence is so unconceivable, and their other *Phænomena* so surprising, that they merit well to be consider'd apart.

What is here said, is to be understood of the Sea Winds at some distance from the Land; for upon and near the Shores, the Land and Sea Brizes are almost every where sensible; and the great Variety which happens in their Periods, Force and Direction, from the situation of the Mountains, Vallies and Woods, and from the various Texture of the Soil, more or less capable of retaining and reflecting Heat, and of exhaling or condensing Vapours is such, that it were an endless task, to endeavour to account for them.



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II. In the *Indian* Ocean, the Winds are partly general, as in the *Æthiopick* Ocean, partly Periodical, that is, half the Year they blow one way, and the other half near upon the oppoſite Points; and theſe Points and Times of ſhifting are diffeent in different parts of this Ocean; the limits of each tract of Sea, ſubject to the ſame change or *Monſoon*, are certainly very hard to determine, but the diligence I have uſed to be rightly inform'd, and the care I have taken therein, has, in a great meaſure, ſurmounted that difficulty, and I am perſwaded that the following particulars may be relied upon.

1. That between the Latitudes of ten Degrees and thirty Degrees South, between *Madagaſcar* and *Hollandia Nova*, the general Trade Wind about the S. E. by E. is found to blow all the Year long, to all Intents and Purpoſes after the ſame manner as in the ſame Latitudes in the *Æthiopick* Ocean, as it is deſcribed in the fourth *Remark* aforeging.

2. That the aforeſaid S. E. Winds extend to within two Degrees of the *Æquator*, during the Months of *June*, *July*, *Auguſt*, &c. to *November*, at which time between the *South Latitudes* of three and ten Degrees, being near the Meridian of the North end of *Madagaſcar*, and between two and twelve South Latitude, being near *Sumatra* and *Java*, the contrary Winds from the N. W. or between the *North* and Weſt, ſet in and blow for half the Year, *viz.* from the beginning of *December* till *May*; and this *Monſoon* is obſerv'd as far as the *Molucca* Iſles, of which more anon.

3. That

3. That to the Northward of three Degrees South Latitude, over the whole *Arabian* or *Indian-Sea* and Gulph of *Bengall*, from *Sumatra* to the Coast of *Africa*, there is another *Monsoon*, blowing from *October* to *April* upon the North East Points; but in the other half Year, from *April* to *October*, upon the opposite Points of S. W. and W. S. W. and that with rather more force than the other accompanied with dark rainy Weather, whereas the N. E. blows clear; 'tis likewise to be noted, that the Winds are not so constant, either in strength or point in the Gulph of *Bengall*, as they are in the *Indian-Sea*, where a certain and steady Gale scarce ever fails. 'Tis also remarkable, that the S. W. Winds in these Seas are generally more Southerly on the *African* side, more Westerly on the *Indian*.

4. That as an *Appendix* to the last described *Monsoon*, there is a Tract of Sea to the Southwards of the Æquator, subject to the same changes of the Winds, *viz.* near the *African* Coast, between it and the Island *Madagascar* or St. *Laurence*, and from thence Northwards as far as the Line; wherein from *April* to *October* there is found a constant fresh S. S. W. Wind, which, as you go more Northerly, becomes still more and more Westerly, so as to fall in with the W. S. W. Winds, mention'd before, in those Months of the Year to be certain to the Northward of the Æquator: What Winds blow in these Seas, for the other half Year, from *October* to *April*, I have not yet been able to obtain to my full satisfaction, for that our Navigators always return from *India* without *Madagascar*, and so are little acquainted in this matter; the Account that has been given me is



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only this, that the Winds are much Easterly hereabouts, and as often to the North of the true East as to the Southwards thereof.

5. That to the Eastward of *Sumatra* and *Malacca*, to the Northwards of the Line, and along the Coast of *Camboia* and *China*, the *Monsoons* blow North and South, that is to say, the N. E. Winds are much Northerly, and the S. W. much Southerly: This Constitution reaches to the Eastwards of the *Philippine* Ilses, and as far Northerly as *Japan*. The Northern *Monsoon* setting in, in these Seas, in *October* or *November*, and the Southern in *May*, blowing all the Summer Months: Here it is to be noted, That the Points of the Compass, from whence the Wind comes in these Parts of the World, are not so fixt as in those lately describ'd, for the Southerly will frequently pass a Point or two to the Eastwards of the South, and the Northerly as much to the Westwards of the North, which seems occasion'd by the great quantity of Land which is interspers'd in these Seas.

6. That in the same *Meridians*, but to the Southwards of the Æquator, being that Tract lying between *Sumatra* and *Java* to the West, and New *Guinea* to the East, the same Northerly *Monsoons* are observ'd, but with this difference, that the inclination of the Northerly is towards the N. W. and of the Southerly towards the S. E. but the *plaga venti* are not more constant here than in the former, *viz.* variable five or six Points; besides the times of the Change of these Winds, are not the same as in the *Chinese* Seas, but about a Month or six Weeks later.

7. That

7. That these contrary Winds do not shift all at once, but in some places the time of the change is attended with Calms, in others with variable Winds; and it is particularly remarkable, that the end of the Westerly *Monsoon* on the Coast of *Coromandel*, and the two last Months of the Southerly *Monsoon* in the Seas of *China* are very subject to be tempestuous: The violence of these Storms is such, that they seem to be of the Nature of the *West-India Hurricanes*, and render the Navigation of these parts very unsafe about that time of the Year. These Tempests are by our Seamen usually term'd, *The breaking up of the Monsoons.*

By reason of the shifting of these Winds, all those that sail in these Seas, are oblig'd to observe the Seasons proper for their Voyages, and so doing they fail not of a fair Wind and speedy Passage; but if so be they chance to out-stay their time till the contrary *Monsoon* set in, as it frequently happens, they are forc'd to give over the hopes of accomplishing their intended Voyages, and either return to the Port from whence they came, or else put in to some other Harbour, there to spend the time till the Winds shall come favourable.

III. The third Ocean call'd *Mare Pacificum*, whose extent is equal to that of the other two (it being from the West Coast of *America* to the *Philippine* Islands, not less than 150 Degrees of Longitude) is that which is least known to our own or the Neighbour Nations; that Navigation that there is on it, is by the *Spaniards*, who go Yearly from the Coast of New *Spain* to the *Manilha's*, but that but by one beaten track so that I cannot be so particular here as in the o-

ther two. What the *Spaniſh* Authors ſay of the Winds they find in their Courſes, and what is confirm'd by the old Accounts of *Drake* and *Candiſh*, and ſince by *Schooten*, who ſail'd the whole breadth of this Sea in the Southern Latitude of fifteen or ſixteen Degrees, is, that there is a great conformity between the Winds of this Sea, and thoſe of the *Atlantick* and *Æthiopick*; that is to ſay, that to the Northwards of the Æquator, the predominant Wind is between the Eaſt and North-Eaſt, and to the Southwards thereof there is a conſtant ſteady Gale between the Eaſt and South-Eaſt, and that on both ſides the Line with ſo much conſtancy, that they ſcarce ever need to attend the Sails, and Strength, that it is rare to fail of croſſing this vaſt Ocean in ten Weeks time, which is about 130 Miles *per diem*; beſides 'tis ſaid that Storms and Tempeſts are never known in theſe parts: So that here is the very beſt of Sailing; no want of a freſh fair Wind, and yet no danger of having too much: Wherefore ſome have thought it might be as ſhort a Voyage to *Japan* and *China*, to go by the Streights of *Magellan*, as by the Cape of *Good-Hope*.

The limits of theſe general Winds are alſo much the ſame as in the *Atlantick* Sea, *viz.* about the thirtieth Degree of Latitude on both ſides; for the *Spaniards* homewards bound from the *Manhilla's*, always take the advantage of the Southerly *Monſoon*, blowing there in the Summer Months, and run up to the Northwards of that Latitude, as high as *Japan*, before they meet with variable Winds, to ſhape their Courſe to the Eaſtwards. And *Schooten* and others that have gone about by the *Magellan* Streights, have found the limits of S. E.

Winds,

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Winds, much about the same Latitude to the Southwards; besides a farther *Analogy* between the Winds of this Ocean, and the *Æthiopick*, appears in that, upon the Coast of *Peru*, they are always much Southerly, like as they are found near the Shores of *Angola*.

Thus far Matter of Fact, wherein if the information I have receiv'd be not in all parts Accurate, it has not been for want of inquiry from those I conceiv'd best able to instruct me; and I shall take it for a very great Kindness if any Master of a Ship, or other Person, well inform'd of the Nature of the Winds, in any of the aforementioned parts of the World, shall please to communicate their Observations thereupon; so that what I have here Collected may be either confirm'd or amended, or by the addition of some material Circumstances enlarg'd. It is not the work of one, nor of few, but of a multitude of Observers, to bring together the experience requisite to compose a perfect and compleat History of these Winds; however I am not much doubtful that I have err'd in, or omitted any of the principal Observables, whatever lesser particulars may have escaped my knowledge.

To help the Conception of the Reader in a manner of so much difficulty, I believ'd it necessary to adjoin a Scheme, *Plate* 2. shewing at one view all the various Tracts and Courses of these Winds; whereby 'tis possible the thing may be better understood, than by any verbal Description whatsoever.

The Limits of these several Tracts are designed every where by prickt Lines, as well in the *Atlantick* and *Æthiopick*, where they are the boundaries of the Trade and variable Winds,

as

as in the *Indian* Ocean, where they alſo ſhew the extent of the ſeveral *Monſoons*. I could think of no better way to deſign the courſe of the Winds on the Map, than by drawing rows of ſtroaks in the ſame Line that a Ship would move going always before it; the ſharp end of each little ſtroak pointing out that part of the Horizon, from whence the Wind continually comes; and where there are *Monſoons*, the rows of the ſtroaks run alternately backwards and forwards, by which means they are thicker there than elſewhere. As to the great South Sea, conſidering its vaſt extent, and the little Variety there is in its Winds, and the great *Analogy* between them, and thoſe of the *Atlantick* and *Æthiopick* Oceans; beſides that the greateſt part thereof is wholly unknown to us; I thought it unneceſſary to lengthen the Map therewith.

In the foregoing Hiſtory are contained ſeveral Problems, that merit well the Conſideration of our acuteſt Naturaliſts, both by reaſon of the conſtancy of the Effect, and of the immenſe Extent thereof; near half the Surface of the Globe being concerned. The chief of theſe Problems are, 1. Why theſe Winds are perpetually from the Eaſt in the *Atlantick* and *Æthiopick*, as likewiſe in the *Pacifick* Ocean, between the Latitudes of 30 North and South. 2. Why the ſaid Winds extend no farther with Conſtancy than to the Latitudes of 30 *deg.* 3. Why there ſhould be a conſtant South-weſterly Wind upon and near the Coaſt of *Guinea*. 4. Why in the North-part of the *Indian* Ocean the Winds, which for one half year do agree with thoſe of the other two Oceans, ſhould change in the other half Year, and blow from the oppoſite Points;

Points; whilst the Southern part of that Ocean follows the General Rule, and has perpetual Winds about S. E. 5. Why in these General Trade-Winds it should be always true, that to the Northward of the *Æquator* it is inclined to the Northwards of the East; and in South Latitudes, to the Southward thereof. 6. Why in these Seas of *China* there should be so great an Inclination from the East to the North, more than elsewhere; with many more, which it would be much easier to propose than answer.

But lest I should seem to propose to others difficulties which I have not thought worth my own time and Pains, take here the result of an earnest Endeavour after the true reason of the aforesaid *Phenomena*, wherein if I am not able to account for all Particulars, yet 'tis hoped the Thoughts I have spent thereon, will not be judged wholly lost, by the curious in Natural Enquiries.

Wind is most properly defined to be the Stream or Current of the Air, and where such a Current is perpetual and fast in its course, 'tis necessary that it proceed from a permanent or intermitting Cause. Wherefore some have been inclined to propose the diurnal *Rotation* of the Earth upon its *Axis*, by which, as the *Globe* turns Eastwards, the loose and *fluid* Particles of the Air, being so exceeding light as they be, are left behind, so that in respect of the Earths *Surface* they move Westwards, and become a constant Easterly Wind. This Opinion seems confirmed, for that these Winds are found only near the *Æquinoctial*, in those Parallels of Latitude where the diurnal Motion is swiftest; and I should readily assent unto it, if the constant Calms in the *Atlantick* Sea, near the *Æquator*, the

the Westerly Winds near the Coast of *Guiny*; and the *Periodical* Westerly *Monsoons* under the *Æquator* in the *Indian* Seas, did not declare insufficiency of that *Hypothesis*. Besides the Air being kept to the Earth by the Principle of *Gravity*, would acquire the same degree of *Velocity* that the Earths *Surface* moves with, as well in respect of the diurnal *Rotation*, as of the Annual about the Sun, which is about thirty times swifter.

It remains therefore to substitute some other cause, capable of producing a like constant effect, not liable to the same Objections, but agreable to the known Properties of the Elements of Air and Water, and the Laws of the Motion of fluid Bodies. Such an one is, I conceive, the Action of the Sun Beams upon the Air and Water, as he passes every day over the Oceans, considered together with the Nature of the Soil, and Situation of the adjoining Continents: I say therefore, first, that according to the Laws of *Staticks*, the Air which is less rarified or expanded by heat, and consequently more ponderous, must have a Motion towards those parts thereof, which are more rarified, and less ponderous, to bring it to an *Æquilibrium*; and secondly, that the Presence of the Sun continually shifting to the Westwards, that part towards which the Air tends, by reason of the Rarifaction made by his greatest *Meridian* Heat, is with him carried Westward, and consequently the tendency of the whole Body of the lower Air is that way.

Thus a general Easterly Wind is formed, which being impressed upon all the Air of a vast Ocean, the Parts impel one the other, and so keep moving till the next return of the Sun, whereby

whereby so much of the Motion as was lost, is again restored, and thus the Westerly Wind is made perpetual.

From the same Principle it follows, that this Easterly Wind should on the North-side of the *Æquator*, be to the Northwards of the East, and in South Latitudes to the Southwards thereof; for near the *Line*, the Air is much more rarified, than at a greater distance from it; because of the Sun twice in a Year Vertical, and at no time distant above 23 deg. and a half; at which distance the Heat, being as the Sine of the Angle of Incidence, is but little short of that of the perpendicular Ray. Whereas under the Tropicks, though the Sun stay long Vertical, yet he is as long 47 deg. off; which is a kind of Winter, wherein the Air so cools, as that the Summer-heat cannot warm it to the same degree with that under the Æquator. Wherefore the Air to the Northwards and Southwards, being less rarified than that in the middle, it follows, that from both sides it ought to tend towards the Æquator: This Motion compounded with the former Easterly Wind answers all the *Phænomena* of the general Trade-winds; which, if the whole Surface of the Globe were Sea, would undoubtedly blow all round the World, as they are found to do in the *Atlantick* and *Æthiopick* Oceans.

But seeing that so great Continents do interpose and break the continuity of the Oceans, regard must be had to the Nature of the Soil, and the Position of the high Mountains, which I suppose the two principal Causes of the several Variations of the Winds, from the former general Rule: For if a Country lying near the Sun, prove to be flat, sandy, low Land, such as

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as the Deserts of *Lybia* are usually reported to be, the Heat occasioned by the Reflection of the Suns Beams, and the retention thereof in the Sand, is incredible to those that have not felt it; whereby the Air being exceedingly rarified, it is necessary that the cooler and more dense Air should run thitherwards to restore the *Æquilibrium*: This I take to be the cause, why near the Coast of *Guinea* the Wind always sets in upon the Land, blowing Westerly instead of Easterly, there being sufficient reason to believe, that the Inland Parts of *Africa* are prodigiously hot, since the Northern Borders thereof were so intemperate, as to give the Ancients cause to conclude, that all beyond the *Tropick* was made inhabitable by excess of Heat: From the same cause it happens, that there are so constant Calms in that part of the Ocean, called the *Rainer*, (described in the 7th Remark on the *Atlantick* Sea) for this Tract being placed in the middle, between the Westerly Winds blowing on the Coast *Guinea*, and the Easterly Trade-winds, blowing to the Westwards thereof, the tendency of the Air here, is indifferent to either, and so stands in *Æquilibrio* between both; and the weight of the incumbent Atmosphere being diminished by the continual contrary Winds blowing from hence, is the reason that the Air here holds not the copious Vapour it receives, but lets it fall into frequent Rains.

But as to the cool and dense Air, by reason of its greater Gravity, presses upon the hot and rarified, 'tis demonstrative that this latter must ascend in a continued stream as fast it rarifies; and that being ascended, it must disperse it self to preserve the *Æquilibrium*; that is, by a contrary

contrary Current, the upper Air must move from those Parts where the greatest Heat is: So by a kind of Circulation, the North-East Trade Wind below, will be attended with a South-Westerly above, and the South Easterly with with a North-West Wind above; that this is more than a bare conjecture, the almost instantaneous change of the Wind to the opposite Point, which is frequently found in passing the limits of the Trade-winds, seems to assure us; but that which above all confirms this *Hypothesis* is the *Phænomenon* of the *Monsoons*, by this means most easily solved, and without it hardly explicable.

Supposing therefore such a Circulation as above, 'tis to be considered that to the Northward of the *Indian* Ocean there is every where Land within the usual limit of the Latitude of 30. *viz. Arabia, Persia, India, &c.* which for the same reason as the *Mediterranean* Parts of *Africa*, are subject to unsufferable Heats when the Sun is to the North, passing nearly Vertical; but yet are temperate enough when the Sun is removed towards the other *Tropick*; because of a ridge of Mountains at some distance within the Land, said to be frequently in Winter covered with Snow, over which the Air, as it passes, must needs be much chilled. Hence it comes to pass, that the Air coming according to the general Rule, out of the *N. E.* in the *Indian* Seas, is sometimes hotter, sometimes colder, than that which by this Circulation is returned out of the *S. W.* and by consequence, sometimes the under Current or Wind is from the N. E. sometimes from the S. W.

That

That this has no other Cause, is clear from the times wherein these Winds set in, *viz.* in *April*, when the Sun begins to warm those Countries to the North, the S. W. *Monsoon* begins, and blows during the Heats till *October*; when the Sun being retir'd, and all things growing cooler Northward, and the Heat increasing to the South, the North-East Winds enter and blow all the Winter till *April* again. And it is undoubtedly from the same Principle that to the Southwards of the Æquator, in part of the *Indian* Ocean, the North-West Winds succeed the South-East, when the Sun draws near the *Tropick* of *Capricorn*; but I must confess, that in this latter occurs a difficulty, not well to be accounted for, which is, why this Change of the *Monsoons* should be any more in this Ocean, than in the same Latitudes in the *Æthiopick*, where there is nothing more certain than a S. E. Wind all the Year.

'Tis likewise very hard to conceive why the limits of the Trade-Wind should be fixt, about the thirtieth Degree of Latitude all round the Globe; and that they should so seldom transgress or fall short of those bounds; as also that in the *Indian* Sea, only the Northern Part should be subject to the changeable *Monsoons*, and in the Southern there be a constant S. E.

These are Particulars that merit to be consider'd more at large, and furnish a sufficient Subject for a just Volume, which will be a very commendable Task for such, who being used to Philosophick Contemplation, shall have leasure to apply their serious Thoughts about it.



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## *A Diſcourſe of the Rule of the Decreaſe of the height of the* Mercury *in the Barometer, according as Places are elevated above the Surface of the Earth; with an Attempt to diſcover the true Reaſon of the Riſing and Falling of the* Mercury, *upon Change of Weather. By* Edm. Halley.

THE Elaſtick Property of the Air has been long ſince made out, by Experiments before the Royal Society and elſewhere; and the Reſiſtance of its Spring is found to be nearly equal to the Weight or Force that compreſſes it; as alſo, that the Spaces the ſame Air occupies, under differing Preſſures, are reciprocally as thoſe Preſſures: It has been ſhown likewiſe by undoubted Experiment, that the ſpecifick Gravity of the Air, near the Earth's Surface to that of Water, was once as 1 to 840; again as 1 to 852; and a third time, in a very large Veſſel holding 10 Gallons, as 1 to 860; all which, conſidering the difficulty of the Experiment, agree well enough, the Mercury ſtanding at all thoſe times about 29 Inches ¼: But by reaſon 'twas Summer-weather, and conſe-



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quently the Air rarified, when all these were tried, we may without sensible Error say in round numbers, that the Barometer standing at 30 Inches, and in a mean State of Heat and Cold, the specifick Gravity of the Air to Water, is as 1 to 800. By the like Trials the Weight of Mercury to Water, is as 13½ to 1, or very near it; so that the weight of Mercury to Air, is as 10800 to 1; and a Cylinder of Air of 10800 Inches or 900 Feet, is equal to an Inch of Mercury; and were the Air of an equal density like Water, the whole Atmosphere would be no more than 5, 1 miles high, and in the Ascent of every 900 Feet the Barometer would sink an Inch. But the Expansion of the Air increasing in the same proportion as the incumbent weight of the Atmosphere decreases; that is, as the Mercury in the Barometer sinks, the upper Parts of the *Air* are much more rarified than the lower, and each Space answering to an Inch of Quicksilver grows greater and greater; so that the Atmosphere must be extended to a much greater height. Now, upon these Principles, to determine the height of the *Mercury* at any assigned height in the *Air*; and *e contra*, having the height of the *Mercury* given, to find the height of the Place where the *Barometer* stands, are Problems not more difficult than curious; and which I thus resolve.

The Expansions of the *Air* being reciprocally as the heights of the *Mercury*, it is evident, that by the help of the Curve of the *Hyperbola* and its *Asymptotes*, the said Expansions may be expounded to any given height of the *Mercury*: For by the 65th *Prop. lib.* 2. *Conic. Mydorgii*, *the Rectangles*, *ABCE*, *AKGE*, *ALDE*, *&c.* (in *Plate* 1. *Fig.* 4.) are always equal, and consequently the

the sides, *CB*, *GK*, *LD*, &c. are reciprocally as the sides *AB*, *AK*, *AL*, &c. If then the Lines *AB*, *AK*, *AL*, be supposed equal to the heights of the *Mercury*, or the pressures of the Atmosphere, the lines *CB*, *KG*, *LD*, answering thereto, will be as the Expansions of the *Air* under those Pressures, or the bulks that the same quantity of *Air* will occupy; which Expansions being taken infinitely many, and infinitely little, (according to the Method of Indivisibles) their Summ will give the Spaces of Air between the several heights of the *Barometer*; that is to say, the Summ of all the Lines between *CB* and *KG*, or the *Area CBKG*, will be proportioned to the distance or space intercepted between the Levels of two Places in the Air, where the *Mercury* would stand at the heights represented by the Lines *AB*, *AK*; so then the Spaces of Air answering to equal Parts of *Mercury* in the *Barometer*, are as the *Area's CBKG*, *GKLD*, *DLFM*, &c. These *Area's* again are, by the Demonstration of *Gregory* of St. *Vincent*, proportionate to the *Logarithms* of the Numbers expressing the *Rationes* of *AK* to *AB*, of *AL* to *AK*, of *AM* to *AL*, &c. So then by the common Table of *Logarithms*, the height of any Place in the *Atmosphere*, having any assigned height of the *Mercury* may most easily be found: For the Line *CB* in the *Hyperbola*, whereof the *Area's* design the *Tabular Logarithms*, being 0, 014476[5]; 'twill be, as 0, 014476[5], to the difference of the *Logarithms* of 30, and any other lesser Number, for 900 Feet or the Space answering to an Inch of *Mercury*, if the Air were equally prest with 30 Inches of *Mercury*, and every where alike, to the height of the *Barometer* in the *Air*, where it

will stand at that lesser number of Inches: And by the Converse of this Proportion may the height of the *Mercury* be found, having the Altitude of the Place given. From these Rules I deriv'd the following Tables.

*A Table shewing the Altitude, to given heights of the* Mercury.

| Inch. | | Feet. |
|---|---|---|
| 30 | | 0 |
| 29 | | 915 |
| 28 | | 1862 |
| 27 | | 2844 |
| 26 | | 3863 |
| 25 | | 4922 |
| 20 | | 10947 |
| 15 | | 18715 |
| 10 | | 29662 |
| 5 | | 48378 |
| 1 | | 91831 |
| 0. 5 | | 110547 |
| 0 25 | | 129262 |
| 0. 1 | 29 mil. or | 154000 |
| 0. 01 | 41 mil. or | 216169 |
| 0. 001 | 53 mil. | 278338 |

*A Table shewing the heights of the* Mercury, *at given Altitudes.*

| Feet | | Inch |
|---|---|---|
| 0 | | 30 00 |
| 1000 | | 28 91 |
| 2000 | | 27 86 |
| 3000 | | 26 85 |
| 4000 | | 25 87 |
| 5000 | feet | 24 93 |
| 1 | mile | 24 67 |
| 2 | | 20 29 |
| 3 | | 16 68 |
| 4 | | 13 72 |
| 5 | | 11 28 |
| 10 | | 4 24 |
| 15 | | 1 60 |
| 20 | | 0 95 |
| 25 | | 0 23 |
| 30 | | 0 08 |
| 40 | | 0 012 |

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UPON theſe Suppoſitions it appears, that at the height of 41 Miles the *Air* is ſo rarified, as to take up 3000 times the Space it occupies here, and at 53 Miles high it would be expanded above 30000 times; but it's probable that the utmoſt Power of its Spring cannot exert it ſelf, to ſo great an Extenſion, and that no part of the *Atmoſphere* reaches above 45 Miles from the Surface of the Earth.

This ſeems confirmed from the Obſervations of the *Crepuſculum*, which is obſerv'd commonly to begin and end when the Summ is about 18 degrees below the Horizon; for ſuppoſing the *Air* to reflect light from its moſt rarified Parts, and that as long as the Sun illuminates any of its *Atoms*, they are viſible to an Eye not intercepted by the Curvity of the Earth, it will follow from *Fig.* 5. *Plate* 1. that the proportion of the height of the whole *Air*, to the Semi-diameter of the Earth, is much about, as 1 to 90, or as the exceſs of the *Secant* of about 8½ degrees to the *Radius*. For if *E* be the Eye of the Obſerver, *S* a Place where the Sun ſets at the end of Twilight in *E*, and the Arch *ECS*, or *TCA* be found 18 degrees, the exceſs of the *Secant* of half thereof *ECH*, would be the height of the *Air*, *viz.* *GH*: But the Beam of the Sun *ASH*, and the Viſual Ray *EH*, do each of them ſuffer a Refraction of about 32 or 33 Minutes, whereby being bent inwards from *H* towards *G*, the height of the *Air* need not be ſo great as if they went ſtreight; and having from the Angle *ECS* taken the double Refraction of the *Horizontal Ray*, the half of the Remainder will be 8½ degrees *Circiter*, whoſe *Secant* being 10,111, it follows that as 10000



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to 111, so the Semi-diameter of the Earth supposed 4000 Miles, to 44, 4 Miles; which will be the height of the whole *Air*, if the Places *E*, *S*, whose visible Portions of the *Atmosphere* *E R Z H*, and *S H K B* just touch one the other, be 18 degrees asunder.

At this height the *Air* is expanded into above 3000 times the space it occupies here, and we have seen the Experience of condensing it into the 60th part of the same Space; so that it should seem, that the Air is a Substance capable of being compressed into the 180000th part of the Space it would naturally take up, when free from pressure. Now what Texture or Composition of Parts shall be capable of this great Expansion and Contraction, seems a very hard Question; and which, I suppose, is scarce sufficiently accounted for, by comparing it to Wool, Cotton, and the like springy Bodies.

Hitherto I have only consider'd the *Air* and *Atmosphere*, as one unalter'd Body, as having constantly at the Earth's Surface the 800th part of the weight of Water, and being capable of Rarefaction and Condensation *in infinitum*; neither of which *Hypotheses* are rigidly true: For here in *England* it's notoriously known, that the weight of the whole *Atmosphere* is various, being counterpoised sometimes by 28½ Inches of *Mercury*, and at other times by no less than 30½; so that the under parts being pressed by about a 15th part, less weight, the *specifick* Gravity of the *Air* upon that score will sometimes be a 15th part lighter than another; besides Heat and Cold does very considerably dilate and contract the Air, and consequently alter its Gravity; to which add the mixture of *Effluvia*, or steams arising from almost all Bodies,

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dies, which assimulating into the Form of Air are kept suspended therein, as Salts dissolv'd in Liquors, or Mettles in corroding *Menstrua*; which Bodies being all of them very much heavier than *Air*, their Particles by their Admixture must needs encrease the weight of that *Air* they lie incorporated withal, after the same manner as melted Salts do augment the specifick Gravity of Water. The other Consideration is, that the Rarefaction and Condensation of the *Air* is not precisely according to the proportion here laid down; for the Experiment very nearly agrees thereto, as may be seen in the 58th Chapter of *Mr. Hook's Micrography*; yet are the Condensations not possible beyond certain degrees: For being compressed into an 800th part of the Space it takes up here, its consistence would be equally dense with that of Water; which yields not to any force whatsoever, as hath been found by several Experiments tried here, and at *Florence*, by the *Academia del Cimento*. Nor can the Rarefaction proceed *in infinitum*; for supposing the Spring whereby it dilates it self, occasion'd by what Texture of Parts you please, yet must there be a determinate Magnitude of the natural State of each Particle, as we see it is in Wool and the like, whose Bodies being compressable into a very small Space, have yet a determinate bulk which they cannot exceed, when free'd from all manner of Pressure.

These Objections being true, do disturb the Geometrical Accuracy of these Conclusions, drawn from the specifick Gravity of the *Air* observ'd at any time; but the Method here shewn will compute by a like Calculation, the heights of the *Quick-silver*, and the Rarefactions

of the *Air* from any assigned height of the *Barometer* at the Earth's Surface, and any specifick Gravity given. As to the Condensation and Rarefaction by Heat and Cold, and the various mixture of Aqueous and other Vapours, these two Objections seem generally to compensate each other; for when the Air is rarified by Heat, they are raised most copiously; so that tho' the *Air* properly so called, be expanded, and consequently lighter, yet the *Interstices* thereof being crouded full of Vapours of much heavier Matters, bulk for bulk, the weight of the *Compositum* may continue much the same; at least a most curious Experiment made by the Ingenious Mr. *John Caswell*, of *Oxford*, upon the top of *Snowdon* Hill, in *Caernarvanshire*, seems to prove, that the first Inches of *Mercury* have their Portions of *Air* near enough to what I now determine: For the height of the Hill being 1240 Yards, or very near it, he found the *Mercury* to have subsided to 25, 6 Inches or 4 Inches below the mean Altitude thereof at the Level of the Sea, (which is a greater difference than has been found in any of our former Experiments,) and the Space answering to 4 Inches, by my Calculation, should be 1288 Yards; and it agrees as well with the Observations in the Appendix to Mr. *Pascall*'s Book, *del' Equilibre des Liqueurs*, made on the high Hill in *Auvergne*, call'd *le puy de Domme*. So that the Rarefaction and Vapours seem not to have altered considerably, the Gravity of the under Parts of the *Air*; and much above the height where these Experiments were made, do few Vapours ascend, and the Cold is such that the Snow lies continually, so that for the more elevated Parts of the Sphere of *Air*, there is much less Reason to doubt.

But

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But now we have had occaſion to mention the difference there is between the height of the *Mercury* at one time, from the height thereof at another, it may not be unacceptable to offer at ſome Reaſons for the ſaid difference; which, at leaſt to my ſelf, ſeem to have ſome appearance of Truth. *Firſt*, then it's undoubtedly demonſtrable, that the height of the Cylinder of *Mercury* is equal to the weight of the whole incumbent *Air*, and conſequently that that whole is ſometimes a fifteenth more than at other times; which cannot otherwiſe be, but by the acceſs of new Matter when 'tis heavy, and its diminution when 'tis light; that *Hypotheſis* therefore that ſhews how the *Air* ſhall be encreaſed or diminiſhed, in any particular place, will give a Reaſon for the greater and leſſer height of the *Mercury* in the *Baroſcope*: But to direct us in the choice of the ſeveral Cauſes, which may be aſſigned for the Increaſe and Decreaſe of the *Air*, 'twill not be unneceſſary to enumerate ſome of the principal Obſervations made upon the *Barometer*, moſt whereof are ſufficiently known already to all thoſe that are curious in theſe Matters.

The *Firſt* is, that in calm Weather when the *Air* is inclined to Rain, the *Mercury* is commonly low.

2. That in ſerene good ſettled Weather the *Mercury* is generally high.

3. That upon very great Winds, tho' they be not accompanied with Rain, the *Mercury* ſinks loweſt of all, with relation to the Point of the Compaſs the Wind blows upon.

4. That

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4. That *ceteris paribus* the greatest heights of the *Mercury* are found upon Easterly and North-Easterly Winds.

5. That in calm frosty Weather the *Mercury* generally stands high.

6. That after very great Storms of Wind, when the *Quicksilver* has been low, it generally rises again very fast.

7. That the more Northerly places have greater alterations of the *Baroscope* than the more Southerly.

8. That within the *Tropicks*, and near them, those Accounts I have had from others, and my own Observation at St. *Helena*, make very little or no Variation of the height of the *Mercury* in all weathers. Now that Theory that can well account for all these appearances, will, in all probability, approach nearer the true cause of the *Barometer's* Variations, than any thing hitherto afforded; and such an one I am bound to believe, is that which I here lay down with submission to better Judgments.

I conceive that the principal Cause of the rise and fall of the *Mercury*, is from the variable Winds, which are found in the *Temperate Zones*, and whose great unconstancy here in *England* is most notorious. I shall not at present inquire into the cause of its uncertainty, but the Matter of Fact being most undoubted, the Legitimate Consequences thereof must be allow'd me, let it proceed from what it will.

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A second Cause is the uncertain Exhalation and Præcipitation of the Vapours lodging in the Air, whereby it comes to be at one time much more crowded than at another, and consequently heavier; but this latter in a great measure depends upon the former. Now from these Principles I shall endeavour to explicate the several *Phænomena* of the *Barometer*, taking them in the same order I laid them down.

1. *Why in Calm Weather the* Air *being inclin'd to Rain, the* Mercury *is commonly low?* I Answer, That the *Mercury*'s being low, inclines it to Rain; for the Air being light, the Vapours are no longer supported thereby, being become specifically heavier than the Medium wherein they floated; so that they descend towards the Earth, and in their fall meeting with other aqueous Particles, they incorporate together, and form little drops of Rain; but the *Mercury*'s being at one time lower than another, is the effect of two contrary Winds blowing from the place whence the *Barometer* stands; whereby the *Air* of that place is carried both ways from it, and consequently the incumbent Cylinder of *Air* is diminish'd, and accordingly the *Mercury* sinks; as for instance, if in the *German Ocean* it should blow a Gale of Westerly Wind, and at the same time an Easterly Wind in the *Irish-Sea*; or if in *France* it should blow a Southerly Wind, and in *Scotland* a Northern; it must be granted me, that That part of the *Atmosphere* impendent over *England*, would thereby be exhausted and attenuated, and the *Mercury* would subside, and the Vapours which before floated in those parts of the *Air* of equal

Gravity

Gravity with themselves, would sink to the Earth.

2. *Why in serene good settled weather the* Mercury *is generally high.* To this I Answer, That the greater height of the *Barometer*, is occasion'd by two contrary Winds blowing *towards* the place of Observation, whereby the *Air* of other places is brought thither and accumulated; so that the incumbent Cylinder of Air being encreased both in height and weight, the *Mercury* press'd thereby must needs rise and stand high, as long as the Winds continue so to blow; and then the Air being specifically heavier, the Vapours are better kept suspended, so that they have no inclination to Præcipitate and fall down in Drops, which is the reason of the serene good Weather, which attends the greater heights of the *Mercury*.

3. *Why upon very great Winds or Storms, though accompanied with no Rain, the* Mercury *sinks lowest of all, with relation to the Point of the Compass upon which the Wind blows.* This is caus'd by the very rapid Motion of the *Air* in these Storms; for the Tract or Region of the Earths Surface, wherein these Winds rage, not extending all round the Globe, that stagnant *Air* which is left behind, as likewise that on the sides, cannot come in so fast as to supply the Evacuation made by so swift a Current; so that the Air must necessarily be attenuated, when and where the said Winds continue to blow, and that more or less according to their violence; add to which, that the *Horizontal* Motion of the *Air* being so quick as it is, may in all probability take off some part of the perpendicular pressure

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pressure thereof; and the great agitation of its Particles, is the Reason why the Vapours are dissipated and do not condense into Drops, so as to form Rain, otherwise the natural Consequence of the *Airs* Rarefaction.

4. *Why* cæteris paribus *the* Mercury *stands highest upon an Easterly or North-Easterly Wind.* This happens because that the great *Atlantick Ocean* on this side the thirty fifth Degree of North Latitude, the Westerly and South-Westerly Winds blow almost always *Trade*; so that whenever here the Wind comes up at East and North-East, 'tis sure to be checked by a contrary Gale, as soon as it reaches the *Ocean*; wherefore, according to what is made out in our second Remark, the *Air* must needs be heaped over this Island; and consequently the *Mercury* must stand high, as often as these Winds blow. This holds true in this Country, but is not a general Rule for others, where the Winds are under different Circumstances; and I have sometimes seen the *Mercury* here as low as twenty nine Inches, upon an Easterly Wind, but then it blows exceeding hard, and so comes to be accounted for by what was observ'd upon the third Remark.

5. *Why in calm Weather the* Mercury *generally stands high.* The cause hereof is, as I conceive, that it seldom freezes but when the Winds come out of the Northern and North-Eastern Quarters, or at least unless those Winds blow at no great distance of; for the Northern Parts of *Germany*, *Denmark*, *Sweeden*, *Norway*, and all that Tract from whence North-Eastern Winds come, are subject to almost continual

tinual Frost all the Winter; and thereby the lower Air is very much condens'd, and in that State is brought hitherwards by these Winds, and being accumulated by the opposition of the Westerly Wind blowing in the Ocean, the *Mercury* must needs be prest to a more than ordinary height, and as a concurring Cause, the shrinking of the lower parts of the *Air* into lesser room by cold, must needs cause a descent of the upper parts of the Atmosphere to reduce the Cavity made by this contraction to an *Equilibrium*.

6. *Why after very great Storms of Wind, when the* Mercury *has been very low, it generally rises again very fast.* This I have frequently observ'd, and once found it risen an Inch and a half in less than six Hours, after a long continu'd Storm of South-West Wind. This seems to be occasion'd by the suddain Accession of new *Air* to supply the great Evacuation which such continu'd Storms make thereof, in those places whence they happen (as in the third Remark) and by the Recoile of the Air, after the force ceases that impell'd it; and the Reason why the *Mercury* rises so fast, is because the Air being very much rarify'd beyond its mean denfity, the Neighbouring *Air* runs in the more swiftly to bring it to an *Equilibration*, as we see Water runs the faster for having a great declivity.

7. *Why in more Northerly places the variations of the* Baroscope *are greater than in the Southerly.* The truth of the Matter of Fact is prov'd from Observations made at *Clermont* and *Paris* compar'd with others, made at *Stockholm* as may be seen in the Appendix to Mr. Pascals Book be-

fore

fore-cited. The Reason I conjecture to be that the more Northerly Parts have usually greater Storms of Wind than the more Southerly, whereby the *Mercury* should sink lower in that extream; and then the Northerly Winds bringing the condens'd and ponderous *Air* from the Neighbourhood of the Pole, and that again being checked by a Southerly Wind, at no great distance, and so heaped must of necessity make the *Mercury* in such case stand higher, in the other extream.

8. And Lastly, *Why near the* Æquinoctial *as at* Barbadoes *and St.* Helena, there is very little or no Variation of the height of the Barometer. This Remark, above all others, confirms the Hypothesis of the variable Winds, being the cause of these Variations of the height of the *Mercury*; for in the places above-named, there is always an easie Gale of Wind blowing nearly upon the same Point, *viz.* E, N, E, at *Barbadoes*, and E, S, E, at St. *Helena*; so that there being no contrary Currents of the Air, to exhaust or accumulate it, the Atmosphere continues much in the same State: However upon Hurricanes, the most violent of Storms, the *Mercury* has been observ'd very low, but this is but for once in two or three Years, and it soon recovers its settled state of about 29½ Inches. I doubt not but the same thing is in the East Coast of *Africa*, and in *India*, where the Monsoons or Winds are Trade for half the Year one way, and half the Year another; only its probable, that there may something worth noting happen, about the times of the change or shifting of the Winds, which might be obtain'd

tain'd if any Body had the curiosity to keep the *Barometer* at our Factories in *India*.

I doubt not but this Doctrine will find some Opposers, and that one principal Objection will be, that I suppose the *Air* sometimes to move *from* those parts where it is already evacuated below the *Equilibrium*, and sometimes again towards those parts, where it is condens'd and crouded above the mean state, which may be thought contradictory to the Laws of Staticks and the Rules of the *Equilibrium* of Fluids. But those that shall consider how, when once an impetus is given to a Fluid Body, it is capable of mounting above its level, and checking others that have a contrary tendency to descent by their own Gravity, will no longer regard this as a material Obstacle, but will rather conclude, that the great *Analogy* there is between the rising and falling of the Water upon the Flux and Reflux of the Sea, and this of the accumulating and extenuating the Air, is a great Argument for the Truth of this Hypothesis: For as the Sea overagainst the Coast of *Essex*, rises and swells by the meeting of the two contrary Tides of Flood, (whereof the one comes from the S. W. along the Channel of *England*, and the other from the North); and on the contrary sinks below its level upon the retreat of the Water both ways in the Tide of Ebb; so it is very probable that the Air may Ebb and Flow, after the same manner; but by reason of the diversity of Causes, whereby the *Air* may be set in moveing, the times of these *Fluxes* and *Refluxes* thereof, are purely Casual and not reducible to any Rule, as are the Motions of the Sea, depending wholly upon the regular Course of the Moon.

A

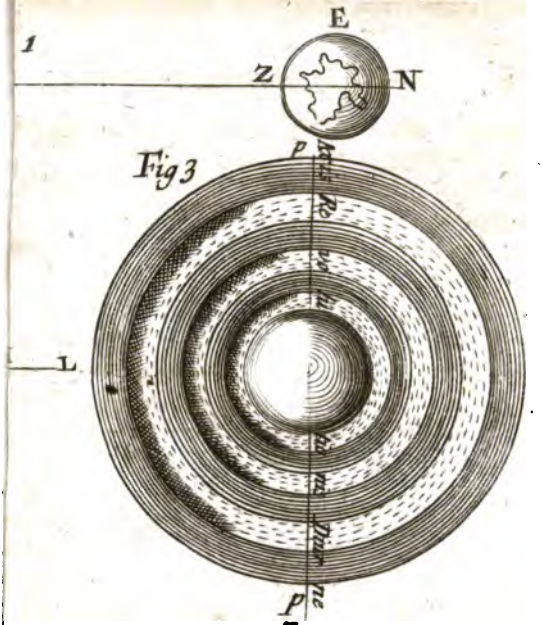


Fig 3

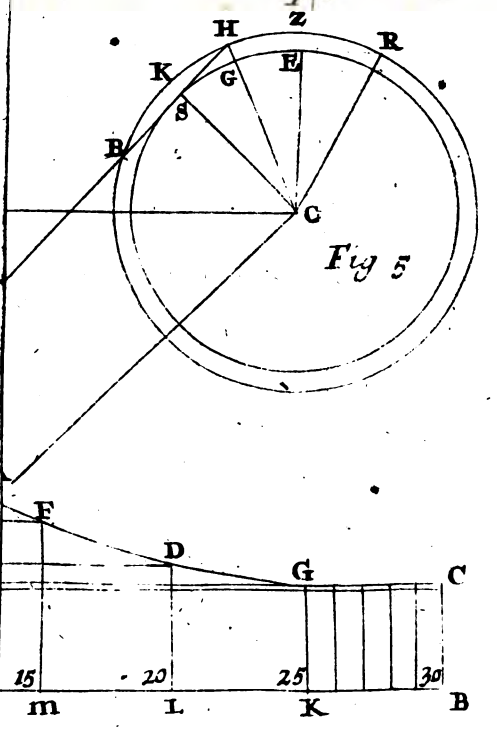


Fig 5




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## *A Letter of Mr.* Isaac Newton, *Professor of the Mathematicks in the University of* Cambridge; *containing his New Theory about* Light *and* Colours: *Sent by the Author to the Publisher from* Cambridge, *Febr.* 6. 16$\frac{71}{72}$; *in order to be communicated to the* R. Society.

*SIR,*

TO perform my late promise to you, I shall without further Ceremony acquaint you, that in the beginning of the Year 1666 (at which time I apply'd my self to the grinding of Optick-glasses of other Figures than *Spherical*,) I procur'd me a Triangular Glass-Prism, to try therewith the celebrated *Phænomena* of *Colours*. And in order thereto having darken'd my Chamber, and made a small hole in my Window-shuts, to let in a convenient quantity of the Suns Light, I plac'd my Prisme at his entrance, that it might be thereby refracted to the opposite Wall. It was at first a very pleasing divertisement, to view the vivid and intense Colours produced thereby; but after a while applying my self to consider them more circumspectly, I became surprised to see them in an *oblong* Form; which, according to the received

ceiv'd Laws of Refraction, I expected ſhould have been *Circular*.

They were terminated at the ſides with ſtreight Lines, but at the ends, the decay of Light was ſo gradual, that it was difficult to determine juſtly, what was their Figure; yet they ſeem'd *Semicircular*.

Comparing the length of this colour'd *Spectrum* with its breadth, I found it about five times greater; a diſproportion ſo extravagant, that it excited me to a more than ordinary Curioſity of examining, from whence it might proceed. I could ſcarce think, that the various thickneſs of the Glaſs, or the termination with ſhadow or darkneſs, could have any Influence on Light to produce ſuch an effect; yet I thought it not amiſs, firſt to examine thoſe Circumſtances, and ſo try'd, what would happen by tranſmitting Light through parts of the Glaſs of divers thickneſſes, or through holes in the Window of divers bigneſſes, or by ſetting the Priſm without ſo, that the light might paſs through it, and be refracted before it was terminated by the hole: But I found none of thoſe Circumſtances material. The faſhion of the Colours was, in all theſe Caſes, the ſame.

Then I ſuſpected, whether by any unevenneſs in the Glaſs, or other contingent Irregularity, theſe Colours might be thus dilated. And to try this, I took another Priſm like the former, and ſo plac'd it, that the light paſſing through them both, might be refracted contrary ways, and ſo by the latter return'd into that Courſe, from which the former had diverted it. For, by this means, I thought the *regular* effects of the firſt Priſm would be deſtroy'd by the ſecond Priſm, but the *irregular* ones more

more augmented by the multiplicity of Refractions. The event was, that the light, which by the first Prism was diffused into an *oblong* Form, was, by the second, reduc'd into an *orbicular* one with as much regularity, as when it did not at all pass through them. So that whatever was the cause of that length, 'twas not any contingent Irregularity.

I then proceeded to examine more critically, what might be effected by the difference of the incidence of Rays coming from divers parts of the Sun; and to that end, measur'd the several Lines and Angles belonging to the Image. Its distance from the Hole or Prism was twenty two Foot; its utmost length 13$\frac{1}{4}$ Inches; its breadth 2$\frac{1}{8}$; the Diameter of the Hole $\frac{1}{4}$ of an Inch; the Angle, with the Rays, tending towards the middle of the Image, made with those Lines, in which they would have proceeded without Refraction, was 44 Deg. 56′. And the Vertical Angle of the Prism, 63 Deg. 12′. Also the Refractions on both sides the Prisme, that is, of the Incident, and Emergent Rays, were as near, as I could make them, equal, and consequently about 54 Deg. 4′. And the Rays fell perpendicularly upon the Wall. Now subducting the Diameter of the Hole from the length and breadth of the Image, there remains 13 Inches the length, and 2$\frac{3}{8}$ the breadth, comprehended by those Rays, which passed through the Center of the said Hole, and consequently the Angle of the Hole, which that breadth subtended, was about 31′, answerable to the Suns Diameter; but the Angle, which its length subtended, was more than five such Diameters, namely two Deg. 49′.



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Having made these Observations, I first computed from them the refractive Power of that Glass, and found it measur'd by the *ratio* of the Sines, twenty to thirty one. And then, by that *ratio*, I computed the Refractions of two Rays flowing from opposite parts of the Sun's *discus*, so as to differ 31′ in their obliquity of Incidence, and found, that the emergent Rays should have comprehended an Angle of about 31′, as they did, before they were incident.

But because this computation was founded on the Hypothesis of the proportionality of the sines of Incidence and Refraction, which, tho' by my own Experience I could not imagine to be so erroneous as to make that Angle but 31′, which in reality was two Deg. 49′; yet my curiosity caus'd me again to take my Prism. And having plac'd it at my Window, as before, I observ'd, that by turning it a little about its *Axis* to and fro, so as to vary its obliquity to the light, more than an Angle of four or five Degrees, the Colours were not thereby sensibly translated from their place on the Wall, and consequently by that variation of Incidence, the quantity of Refraction was not sensibly varied. By this Experiment therefore, as well as by the former computation, it was evident, that the difference of the Incidence of Rays, flowing from divers parts of the Sun could not make them, after decussation, diverge at a sensibly greater Angle, than that at which they before converged; which being, at most, but about thirty one or thirty two Minutes, there still remain'd some other cause to be found out, from whence it could be two Deg. 49′.

Then

Then I began to ſuſpect, whether the Rays, after their Trajection through the Priſm, did not move in curve Lines, and according to their more or leſs Curvity tend to divers parts of the Wall. And it increas'd my ſuſpicion, when I remember'd that I had often ſeen a Tennis-Ball, ſtruck with an oblique Racket, deſcribe ſuch a curve Line. For, a Circular as well as a Progreſſive Motion being communicated to it by that ſtroak, its parts on that ſide, where the Motions conſpire, muſt preſs and beat the contiguous Air more violently than on the other, and there excite a reluctancy and reaction of the Air proportionably greater. And for the ſame reaſon, if the Rays of Light ſhould poſſibly be globular Bodies, and by their oblique Paſſage out of one Medium into another, acquire a circulating Motion, they ought to feel the greater reſiſtence from the ambient Æther, on that ſide, where this Motions conſpire, and thence be continually bowed to the other. But notwithſtanding this plauſible ground of ſuſpicion, when I came to examine it, I could obſerve no ſuch Curvity in them. And beſides (which was enough for my purpoſe) I obſerv'd, that the difference 'twixt the length of the Image, and Diameter of the Hole, through which the light was tranſmitted, was proportionable to their diſtance.

The gradual removal of theſe ſuſpicions, at length led me to the *Experimentum Crucis*, which was this; I took two Boards, and plac'd one of them cloſe behind the Priſm at the Window, ſo that the light might paſs through a ſmall hole, made in it for the purpoſe, and fall on the other Board, which I plac'd at about twelve Feet diſtance, having firſt made a ſmall



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hole in it also, for some of that incident Light to pass through. Then I plac'd another Prism behind this second Board, so that the Light, trajected through both the Boards, might pass through that also, and be again refracted before it arrived at the Wall. This done, I took the first Prism in my Hand, and turn'd it to and fro slowly about its *Axis*, so much as to make the several parts of the Image, cast on the second Board, successively pass through the hole in it, that I might observe to what places on the Wall the second Prism would refract them. And I saw by the variation of those places, that the Light, tending to that end of the Image, towards which the Refraction of the first Prism was made, did, in the second Prism, suffer a Refraction considerably greater than the Light tending to the other end. And so the true cause of the length of that Image was detected to be no other, than that *Light* consists of *Rays differently refrangible*, which, without any respect to a difference in their incidence, were, according to their degrees of refrangibility, transmitted towards divers parts of the Wall.

When I understood this I left off my aforesaid Glass Works; for I saw, that the perfection of Telescopes was hitherto limited, not so much for want of Glasses truly figured according to the prescriptions of Optick-Authors (which all Men have hitherto imagin'd), as because that Light itself is a *Heterogeneous mixture of differently refrangible Rays*. So that, were a Glass so exactly figured, so as to collect any one sort of Rays into one Point, it could not collect those also into the same point, which having the same Incidence upon the same Medium are apt to suffer

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suffer a different Refraction. Nay, I wonder'd, that seeing the difference of Refrangibility was so great, as I found it, Telescopes should arrive to that perfection they are now at. For, measuring the Refractions in one of my Prismes, I found, that, supposing the common Sine of Incidence upon one of its plains, was fourty four Parts, the Sine of Refraction of the utmost Rays on the red end of the Colours, made out of the Glass into the Air, would be sixty eight parts, and the Sine of Refraction of the the utmost Rays on the other end, sixty nine parts; so that the difference is about a twenty fourth or twenty fifth part of the whole Refraction. And consequently, the Object-glass of any Telescope cannot collect all the Rays, which come from one point of an Object, so as to make them convene at its *focus* in less room than in a Circular space, whose Diameter is the fiftieth part of the Diameter of its Aperture; which is an irregularity, some hundreds of times greater, than a circularly figured *Lens*, of so small a section as the Object-glasses of long Telescopes are, would cause by the unfitness of its Figure, were Light *uniform*.

This made me take *Reflections* into consideration, and finding them regular, so that the Angle of Reflection of all sorts of Rays was equal to their Angle of Incidence; I understood, that by their mediation, Optick Instruments might be brought to any degree of Perfection imaginable, provided a *Reflecting* Substance could be found, which would polish as finely as Glass, and *reflect* as much Light as Glass *transmits*, and the art of communicating to it a *Parabolick* Figure be also attain'd. But there seem'd very great difficulties, and I have al-



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most thought them insuperable, when I further consider'd, that every irregularity in a reflecting Superficies makes the Rays stray five or six times more out of their due course, than the like irregularities in a refracting one: So that a much greater curiosity would be here requisite, than in Figuring Glasses for Refraction.

Amidst these Thoughts I was forc'd from *Cambridge* by the Intervening Plague, and it was more than two Years before I proceeded further. But then having thought on a tender way of polishing, proper for Metal, whereby, as I imagin'd, the Figure also would be corrected to the last; I began to try, what might be effected in this kind, and by degrees so far perfected an Instrument (in the essential parts of it like that I sent to *London*,) by which I could discern *Jupiters* four Concomitants, and shew'd them divers times to two others of my Acquaintance. I could also discern the Moon-like Phase of *Venus*, but not very distinctly, nor without some niceness in disposing the Instrument.

From that time I was interrupted till this last Autumn, when I made the other. And as that was sensibly better than the first (especially for Day-Objects,) so I doubt not but they will be still brought to a much greater perfection by their endeavours, who, as you inform me, are taking care about it at *London*.

I have sometimes thought to make a *Microscope*, which in like manner should have, instead of an Object-glass, a reflecting piece of Metal. And this I hope they will also take into consideration: For those Instruments seem as capable of improvement as *Telescopes*, and perhaps

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perhaps more, because but one reflective piece of Metal is requisite in them, as you may perceive in *Plate* 3. *Fig.* 1. where *AB* represenſteth the Object Metal, *CD* the Eye-glass, *F* their common Focus, and *O* the other Focus of the Metal, in which the Object is placed.

But to return from this digression, I told you, that Light is not similar, or homogeneal, but consists of *difform* Rays, some of which are more refrangible than others: So that of those, which are alike incident on the same Medium, some shall be more refracted than others, and that not by any virtue of the Glass, or other external Cause, but from a predisposition, which every particular Ray hath to suffer a particular degree of Refraction.

I shall now proceed to acquaint you with another more notable deformity in its Rays, wherein the *Origin of Colours* is unfolded: Concerning which I shall lay down the *Doctrine* first, and then, for its examination, give you an Instance or two of the *Experiments*, as a Specimen of the rest.

The Doctrine you will find comprehended and illustrated in the following Propositions.

1. As the Rays of Light differ in degrees of Refrangibility, so they also differ in their disposition to exhibit this or that particular Colour. Colours are not *Qualifications of Light*, derived from Refractions, or Reflections of natural Bodies (as 'tis generally believed) but *Original* and *connate Properties*, which in divers Rays are divers. Some Rays are disposed to exhibit a red Colour and no other; some a yellow and no other, some a green and no other, and so of the rest. Nor are there only Rays proper and particular to the more eminent Colours,

lours, but even to all their intermediate Gradations.

2. To the same degree of Refrangibility ever belongs the same Colour, and to the same Colour ever belongs the same degree of Refrangibility. The *least Refrangible* Rays are all disposed to exhibit a *Red* Colour, and contrarily those Rays, which are disposed to exhibit a *Red* Colour, are all the least refrangible: So the *most Refrangible* Rays are all disposed to exhibit a deep *Violet Colour*, and contrarily those which are apt to exhibit such a Violet Colour, are all the most Refrangible. And so to all the intermediate Colours in a continued Series belong intermediate degrees of Refrangibility. And this Analogy 'twixt Colours, and Refrangibility, is very precise and strict; the Rays always either exactly agreeing in both, or proportionally disagreeing in both.

3. The Species of Colour, and degree of Refrangibility proper to any particular sort of Rays, is not mutable by Refraction, nor by Reflection from natural Bodies, nor by any other cause, that I could yet observe. When any one sort of Rays hath been well parted from those of other kinds, it hath afterwards obstinately retained its Colour, notwithstanding my utmost Endeavours to change it. I have refracted it with Prismes, and reflected it with Bodies, which in Day-light were of other Colours; I have intercepted it with the coloured Film of Air interceding two compressed Plates of Glass; transmitted it through coloured Mediums, and through Mediums irradiated with other sorts of Rays, and diversly terminated it; and yet could never produce any new Colour out

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out of it. It would by contracting and dilating become more brisk, or faint, and by the loss of many Rays, in some cases very obscure and dark; but I could never see it changed *in specie.*

Yet seeming Transmutations of Colours may be made, where there is any mixture of divers sorts of Rays. For in such Mixtures, the component Colours appear not, but, by their mutual allaying each other, constitute a midling Colour. And therefore, if by Refraction, or any other of the aforesaid Causes, the difform Rays, latent in such a mixture, be separated, there shall emerge Colours different from the colour of the Composition. Which colours are not new generated, but only made apparent by being parted; for if they be again intirely mix'd and blended together, they will again compose that Colour, which they did before separation. And for the same reason, Transmutations made by the convening of divers Colours are not real; for when the difform Rays are again severed, they will exhibit the very same Colours, which they did before they entered the Composition; as you see, *Blue* and *Yellow* Powders, when finely mixed, appear to to the naked Eye *Green*, and yet the Colours of the component Corpuscles are not thereby really transmuted, but only blended. For, when viewed with a good Microscope, they still appear *Blue* and *Yellow* interspersedly.

5. There are therefore two sorts of Colours. The one original and simple, the other compounded of these. The Original or primary Colours are, *Red*, *Yellow*, *Green*, *Blue*, and a *Violet-purple*, together with Orange, Indico, and an indefinite variety of intermediate Gradations.

6. The

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6. The same Colours in *Specie* with these primary ones, may be also produced by Composition: For, a mixture of *Yellow* and *Blue* makes *Green*; of *Red* and *Yellow*, makes *Orange*; of *Orange* and *Yellowish green*, makes *Yellow*. And in general, if any two Colours be mixed, which in the Series of those, generated by the Prisme, are not too far distant one from another, they by their mutual alloy compound that Colour, which in the said Series appeareth in the midway between them. But those, which are situated at too great a distance, do not so. *Orange* and *Indico* produce not the intermediate Green, nor Scarlet and Green the intermediate Yellow.

7. But the most surprising and wonderful Composition was that of *Whiteness*. There is no one sort of Rays which alone can exhibit this. 'Tis ever compounded, and to its Composition are requisite all the aforesaid primary Colours, mixed in a due proportion. I have often with admiration beheld, that all the Colours of the Prism being made to converge, and thereby to be again mixed as they were in the light before it was incident upon the Prism, reproduced light, intirely and perfectly white, and not at all sensibly differing from a *direct* Light of the Sun, unless when the Glasses, I used, were not sufficiently clear; for then they would a little incline it to *their* Colour.

8. Hence therefore it comes to pass, that *Whiteness* is the usual Colour of *Light*; for, Light is a confused aggregate of Rays indued with all sorts of Colours, as they are promiscuously darted from the various Parts of luminous Bodies. And of such a confused aggregate, as I said, is generated Whiteness, if there be a due

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due proportion of the Ingredients; but if any one predominate, the Light must incline to that Colour; as it happens in the blue Flame of Brimstone, the yellow Flame of a Candle, and the various Colours of the fixed Stars.

9. These things considered, the *manner*, how Colours are produced by the Prism, is evident. For, of the Rays, constituting the incident Light, since those which differ in Colour proportionally differ in Refrangibility, *they* by their unequal Refractions must be severed and dispersed into an oblong Form, in an orderly succession from the least refracted Scarlet to the most refracted Violet. And for the same reason it is, that Objects, when looked upon through a Prism, appear coloured. For, the difform Rays, by their unequal Refractions, are made to diverge towards several Parts of the *Retina*, and there express the Images of things coloured, as in the former case they did the Sun's Image upon a Wall. And by this inequality of Refractions, they become not only coloured, but also very confused and indistinct.

10. Why the Colours of the *Rainbow* appear in falling drops of Rain, is also from hence evident. For, those drops, which refract the Rays, disposed to appear purple, in greatest quantity to the Spectators Eye, refract the Rays of other sorts so much less, as to make them pass beside it; and such are the drops on the inside of the *Primary* Bow, and on the outside of the *Secondary* or Exteriour one. So those drops, which refract in greatest plenty the Rays, apt to appear red, toward the Spectator's Eye, refract those of other sorts so much more, as to make them pass beside it; and such are the

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drops on the exteriour part of the *Primary*, and interiour part of the *Secondary* Bow.

11. The odd Phænomena of an infusion of *Lignum Nephriticum*, *Leaf-gold*, *Fragments of coloured Glass*, and some other transparently coloured Bodies, appearing in one Position of one Colour, and of another in another, are on these grounds no longer Riddles. For, those are Substances apt to reflect one sort of Light, and transmit another; as may be seen in a dark room, by illuminating them with similar or uncompounded Light. For, then they appear of that Colour only, with which they are illuminated; but yet in one Position more vivid and luminous than in another, accordingly as they are disposed more or less to reflect or transmit the incident Colour.

12. From hence also is manifest the reason of an unexpected Experiment, which Mr. *Hook* somewhere in his *Micrography* relates to have made with two wedge-like transparent Vessels, fill'd the one with a red, the other with a blue Liquor; namely, that though they were severally transparent enough, yet both together became opake: For, if one transmitted only red, and the other only blue, no Rays could pass through both.

13. I might add more Instances of this Nature; but I shall conclude with this general one, that the Colours of all natural Bodies have no other Origin than this, that they are variously qualified to reflect one sort of Light in greater plenty than another. And this I have experimented in a dark room, by illuminating those Bodies with uncompounded Light of divers Colours. For by that means any body may be made to appear of any Colour. They have there

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there no appropriate Colour, but ever appear of the Colour of the Light caſt upon them; but yet with this difference, that they are moſt brisk and vivid in the Light of their own day-light-colour. *Minium* appeareth there of any Colour indifferently, with which 'tis illuſtrated, but yet moſt luminous in red; and ſo *Biſe* appeareth indifferently of any Colour with which 'tis illuſtrated, but yet moſt luminous in blue. And therefore *Minium* reflecteth Rays of any Colour, but moſt copiouſly thoſe endued with red; and conſequently when illuſtrated with day-light, that is, with all ſorts of Rays promiſcuouſly blended, thoſe qualified with red ſhall abound moſt in the reflected Light, and by their prevalence cauſe it to appear of that Colour. And for the ſame reaſon *Biſe*, reflecting blue moſt copiouſly, ſhall appear blue by the exceſs of thoſe Rays in its reflected Light; and the like of other Bodies. And that this is the intire and adequate cauſe of their Colours, is manifeſt, becauſe they have no power to change or alter the Colours of any ſort of Rays incident apart, but put on all Colours indifferently, with which they are inlightned.

Theſe things being ſo, it can be no longer diſputed, whether there be Colours in the dark, nor whether they be the Qualities of the Objects we ſee, no nor perhaps, whether Light be a Body. For, ſince Colours are the *Qualities* of Light, having its Rays for their intire and immediate Subject, how can we think thoſe Rays *Qualities* alſo, unleſs one Quality may be the ſubject of and ſuſtain another; which in effect is to call it *Subſtance*. We ſhould not know Bodies for Subſtances, were it not for their ſenſible Qualities; and the principal of thoſe being now found

found due to something else, we have as good reason to believe that to be a Substance also.

Besides, whoever thought any Quality to be a *heterogeneous* aggregate, such as Light is discovered to be? But, to determine more absolutely, what Light is, after what manner refracted, and by what modes or actions it produceth in our Minds the Phantasms of Colours, is not so easie. And I shall not mingle Conjectures with Certainties.

Reviewing what I have written, I see the Discourse it self will lead to divers Experiments sufficient for its Examination; and therefore I shall not trouble you farther, than to describe one of those, which I have already insinuated.

In a darkened Room, make a hole in the shut of a Window, whose Diameter may conveniently be about a third part of an Inch, to admit a convenient quantity of the Sun's Light: And there place a clear and colourless Prism, to refract the entring Light towards the farther part of the room; which, as I said, will thereby be diffused into an oblong coloured Image. Then place a *Lens* of about three Foot Radius (suppose a broad Object-glass of a three Foot Telescope,) at the distance of about four or five Foot from thence, through which all those Colours may at once be transmitted, and made by its Refraction to convene at a farther distance of about ten or twelve Feet. If at that distance you intercept this Light with a sheet of white Paper, you will see the Colours converted into whiteness again by being mingled. But it is requisite, that the *Prism* and *Lens* be placed steddy, and that the Paper, on which the Colours are cast, be moved to and fro; for, by such motion, you will not only find at what distance

the whiteness is most perfect, but also see, how the Colours gradually convene, and vanish into whiteness; and afterwards, having crossed one another in that place where they compound Whiteness, are again dissipated and severed, and in an inverted order retain the same Colours, which they had before they entered the Composition. You may also see, that, if any of the Colours at the *Lens* be intercepted, the Whiteness will be changed into the other Colours. And therefore, that the Composition of whiteness be perfect, care must be taken that none of the Colours fall besides the *Lens*.

In the annexed Design, *Tab.* 3. *Fig.* 2. of this Experiment, *A B C* expresseth the Prism set endwise to sight, close by the hole *F* of the Window *E G*. Its vertical Angle *A B C* may conveniently be about 60 degrees: *M N* designeth the *Lens*. Its breadth $2\frac{1}{2}$ or 3 Inches. *S F* one of the streight Lines, in which differn Rays may be conceived to flow successively from the Sun. *F P*, and *F R* two of those Rays unequally refracted, which the *Lens* makes to converge towards Q, and after decussation to diverge again. And H I the Paper, at divers distances, on which the Colours are projected which in *Q* constitute *Whiteness*, but are *Red* and *Yellow* in *R*, *r*, and *ρ*, and *Blue* and *Purple* in *P*, *p*, and *π*.

If you proceed further to try the impossibility of changing any uncompounded Colour (which I have asserted in the third and thirteenth Propositions,) 'tis requisite that the Room may be very dark, lest any scattering light, mixing with the Colour, disturb and allay it, and render it compound, contrary to the design of the Experiment. 'Tis also requisite, that there be

a perfecter separation of the Colours, than, after the manner above described, can be made by the Refraction of one single Prism; and how to make such farther separations, will scarce be difficult to them, that consider the discovered Laws of Refractions. But if trial shall be made with Colours not througly separated, there must be allowed changes proportionable to the mixture. Thus if compound Yellow light fall upon blue *Bise*, the Bise will not appear perfectly yellow, but rather green, because there are in the yellow mixture many Rays indued with green, and green being less remote from the usual blue Colour of Bise than yellow, is the more copiously reflected by it.

In like manner, if any one of the Prismatick Colours, suppose red, be intercepted, on design to try the asserted impossibility of reproducing that Colour out of the others which are pretermitted; 'tis necessary, either that the Colours be very well parted before the red be intercepted; or that, together with the red, the neighbouring Colours, into which any red is secretly dispersed, (that is, the yellow, and perhaps green too) be intercepted; or else, that allowance be made for the emerging of so much red out of the yellow green, as may possibly have been diffused, and scatteringly blended in those Colours. And if these things be observed, the new Production of red, or any intercepted Colour will be found Impossible.

This, I conceive, is enough for an Introduction to Experiments of this kind; which if any of the *Royal Society* shall be so curious as to prosecute, I should be very glad to be informed with what success: That, if any thing seem to be defective, or to thwart this Relation, I may

have an opportunity of giving farther Direction about it, or of acknowledging my Errors, if I have committed any.

*Since the Publication of this Theory, some Misunderstandings happening between a* French *Philosopher at* Paris *and Mr.* Newton, *he has endeavour'd to explain himself a little further in these Things according to the following Method.*

## DEFINITIONS.

1. I call that Light Homogeneal, Similar, or Uniform whose Rays are equally refrangible.

2. And that Heterogeneal, whose Rays are unequally refrangible.

*Note*, There are but three Affections of Light in which I have observed its Rays to differ; *viz.* Refrangibility, Reflexibility, and Colour; and those Rays which agree in Refrangibility agree also in the other two, and therefore may well be defined Homogeneal; especially since Men usually call those things Homogeneal, which are so in all Qualities that come under their Knowledge, 'though in other Qualities that their Knowledge extends not to, there may possibly by some Heterogeneity.

3. Those Colours I call Simple or Homogeneal, which are exhibited by Homogeneal Light.

4. And those Compound or Heterogeneal, which are exhibited by Heterogeneal Light.

5. Different Colours, I call, not only the more eminent Species Red, Yellow, Green, Blue, Purple, but all other the minutest Gradations;



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much after the same manner, that not only the more eminent Degrees in Musick, but all the least Gradations, are esteemed different Sounds.

## *PROPOSITIONS.*

1. The Sun's Light consists of Rays differing by indefinite Degrees of Refrangibility.

2. Rays which differ in Refrangibility, when parted from one another, do proportionally differ in the Colours which they exhibit. These Two Propositions are Matter of Fact.

3. There are as many Simple or Homogeneal Colours, as Degrees of Refrangibility. For to every Degree of Refrangibility belongs a different Colour, by *Prop.* 2. and that Colour is simple, by *Def.* 1. and 3.

4. Whiteness, in all respects like that of the Sun's immediate Light, and of all the usual Objects of our Senses, cannot be compounded of two simple Colours alone. For such a Composition must be made by Rays that have only two Degrees of Refrangibility, by *Def.* 1, and 3. and therefore it cannot be like that of the Sun's Light, by *Prop.* 1. nor, for the same Reason, like that of ordinary white Objects.

5. Whiteness, in all respects, like that of the Sun's immediate Light, cannot be compounded of simple Colours without an indefinite Variety of them. For to such a Composition, there are requisite Rays endued with all the indefinite Degrees of Refrangibility, by *Prop.* 1. And those infer as many simple Colours, by *Def.* 1, and 3. and *Prop.* 2, and 3.

To make these a little plainer, I have added also the Propositions that follow.

6. The

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6. The Rays of Light do not act on one another, in paſſing thro' the ſame Medium.

7. The Rays of Light ſuffer not any change of their Qualities from Refraction.

8. Nor afterwards from the adjacent quiet *Medium*: Theſe two Propoſitions are manifeſt *de Facto* in Homogeneal Light, whoſe Colour and Refrangibility is not at all changeable, either by Refraction, or by the contermination of a quiet *Medium*. And as for Heterogeneal Light, it is but an Aggregate of ſeveral ſorts of Homogeneal Light, no one ſort of which ſuffers any more alteration than if it were alone; becauſe the Rays act not on one another, by *Prop.* 6. and therefore the Aggregate can ſuffer none. Theſe two Propoſitions alſo might be further proved apart, by Experiments too long to be here deſcribed.

9. There can no Homogeneal Colours be educed out of Light by Refraction, which were not commixt in it before: Becauſe by *Prop.* 7, and 8. Refraction changeth not the Qualities of the Rays, but only ſeparates thoſe which have divers Qualities, by means of their different Refrangibility.

10. The Sun's Light is an Aggregate of an indefinite Variety of Homogeneal Colours, by *Prop*, 1, 3, and 9. And hence it is, that I call Homogeneal Colours alſo Primitive or Original. And thus much concerning Colours.

*For a further Illuſtration of this Doctrin, Mr.* Newton, *in his Book of Opticks lately publiſhed, has by undeniable Experiments explained moſt of the Principal Phænomena of Light and Colours: To which we refer the Reader.*



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## *A Demonstration concerning the Motion of Light, communicated from* Paris.

PHilosophers have been labouring for many Years to decide by some Experiment, whether the Action of Light be conveyed in an instant to distant Places, or whether it requireth time. M. *Romer*, of the *Royal Academy* of Sciences, hath devised a way taken from the Observations of the first Satellit of *Jupiter*, by which he demonstrates, that for the distance of about 3000 Leagues, such as is very near the bigness of the Diameter of the Earth, Light needs not one Second of Time.

Let (in *Fig.* 3. *Plate* 3.) *A* be the *Sun*, *B* *Jupiter*, *C* the first Satellit of *Jupiter*, which enters into the shadow of *Jupiter*, to come out at *D*, and let *EFGHKL* be the *Earth*, placed at divers distances from *Jupiter*.

Now suppose the *Earth*, being in *L* towards the second Quadrature of *Jupiter*, hath seen the first Satellit, at the time of its emersion, or issuing out of the shadow at *D*, and that about $42\frac{1}{2}$ hours after (*viz.* after one Revolution of this *Satellit*) the *Earth* being in *K*, do see it returned in *D*: It is manifest, that if the Light require time to traverse the Interval *LK*, the *Satellit* will be seen returned later in *D*, than it would have been if the *Earth* had remained in *L*. So that the Revolution of the *Satellit* being thus observed by the Emersions, will be retarded

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ded by so much time, as the Light shall have taken in passing from *L* to *K*; and that on the contrary, in the other Quadrature *F G*, where the *Earth* by approaching goes to meet the Light, the Revolutions of the Emersions will appear to be shortned, by so much as those of the Emersions had appear'd to be lengthned. And because $42\frac{1}{2}$ hours, which this *Satellit* very near takes to make one Revolution, the distance between the *Earth* and *Jupiter*, in both the Quadratures, varies at least 210 Diameters of the *Earth*: It follows, that if for the Account of every Diameter of the *Earth* there were required a Second of Time, the Light would take $3\frac{1}{2}$ Minutes for each of the Intervals *G F*, *K L*, which would cause near half a quarter of an Hour between two Revolutions of the first *Satellit*, one observed in *F G*, and the other in *K L*, whereas there is not observed any sensible difference.

Yet doth it not follow hence, that Light demands no time. For after M. *Römer* had examin'd the thing more nearly, he found that what was not sensible in two Revolutions, became very considerable in many being taken together; and that, for Example, forty Revolutions observed on the side *F*, might be sensibly shorter, than forty others observed in any place of the *Zodiack* where *Jupiter* may be met with; and that in proportion of Twenty two for the whole Interval of *H E*, which is the double of the Interval that is from hence to the Sun.

The Necessity of this new Equation of the retardment of Light, is established by all the Observations that have been made in the *Royal Academy*, and in the *Observatory*, for the space of eight Years; and it hath been lately confir-



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med by the Emersion of the first *Satellit* observed at *Paris*, the 9th of *November* last, at 5 a-clock 35′ 45″ at night, 10 minutes later than it was to be expected, by deducting it from those that had been observed in the Month of *August*, when the *Earth* was much nearer to *Jupiter*; which M. *Romer* had predicted to the said Academy from the beginning of *September*.

But to remove all doubt, that this Inequality is caused by the retardment of the Light, he demonstrates, that It cannot come from any Excentricity or other cause of those that are commonly alledged to explicate the Irregularities of the *Moon*, and the other Planets; tho' he be well aware, that the first *Satellit* of *Jupiter* was excentrick; and that, besides his Revolutions were advanced or retarded, according as *Jupiter* did approach to or recede from the Sun; as also, that the Revolutions of the *Primum Mobile* were unequal: Yet, saith he, these three last causes of Inequality do not hinder the first from being manifest.

An

## *An introductory* Eſſay *to the Doctrine of* Sounds, *containing ſome Propoſals for the improvement of* Acouſticks; *As it was preſented to the* Dublin Society, *Nov.* 12. 1683, *by the Right Reverend Father in God* Narciſſus *Lord Biſhop of* Ferns *and* Leighlin.

BEing to treat of the Doctrine of *Sounds*, I hold it convenient to premiſe ſomething in the general concerning this Theory; which may ſerve at once to ingage your Attention, and excuſe my pains, when I ſhall have recommended them, as beſtow'd on a Subject not altogether uſeleſs and unfruitful.

And for this purpoſe I ſhall omit to ſpeak any thing of the *Excellency* of the Matter in Hand; tho' it might be celebrated by Arguments drawn from ſeveral Topicks, and particularly from this, that new Diſcoveries and Improvements may be made both as to the *Generation*, *Propagation* and *Reception* of Sounds into the Senſe; which, in a peculiar manner agrees to this, above the Object of any other Senſe whatſoever. I ſhall, I ſay, omit theſe things, and apply my ſelf wholly to the *Uſefulneſs* of the Theory, that we are now falling upon; which I think cannot better be diſcovered, than by making a compariſon 'twixt the Senſes

Senses of *Seeing* and *Hearing* as to their Improvements. I mean, by shewing, that this latter of *Hearing* is capable of all those improvements which the Sense of *Seeing* has receiv'd from Art, besides many more advantages that the *Ear* may enjoy, by the help of our Doctrine, above the *Eye*; all which moreover will be of as great benefit to Mankind, as any thing that *Opticks* have yet discover'd, if not of greater; which, with some other preeminencies that it has upon another Score, will happily render *Acousticks* the nobler Science of the two.

In order to the making good what I but now promised of the Comparison of these two Faculties of *Seeing* and *Hearing*, as to their Improvements, I observe,

That *Vision* is threefold, *Direct*, *Refracted*, and *Reflex'd*; answerable whereunto we have *Optick*, *Dioptricks*, and *Catoptricks*.

In like manner *Hearing* may be divided into *Direct*, *Refracted* and *Reflex'd*; whereto answer three parts of our Doctrine of *Acousticks*, which are yet nameless, unless we call them *Acousticks*, *Diacousticks*. and *Cathacousticks*, or (in another Sense, but to as good Purpose) *Phonicks*, *Diaphonicks*, and *Cataphonicks*.

1. Direct Vision has been improv'd two ways, *ex parte* Objecti, and *ex parte* Organi *vel* Medii.

1. *Ex parte Objecti* Direct Vision has receiv'd advantages by the Arts of *Producing*, *Conserving* and *Imitating Light* and *Colours*, which are the Objects of Vision.

1. For the Art of *Producing Light*, we have the Frication of all hard Bodies that beget Fire; especially of the Flint and Steel; and instead

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instead of the Flint, most hard Stones (as well as the Cane) may be us'd to the same effect, as upon trial I have found. Add hereto the lately invented *Phosphorus*, which is a new and admirable way of producing a *Lucid Substance* by Art, out of a Body in itself not *Lucid*; and therefore may not unfitly be term'd an *Artificial production* of *Light*.

And then of the Art of *Conserving Light*, the *Lapis Bononiensis* is a notable instance; and so happily were the *Sepulchral Lamps* of the Ancients.

2. As to *Colours*, 'tis the greatest part of the Art of *Dying* to be able to make and fix (that is preserve) them; and the *Painters* and *Limners* will own it to be no small part of their Skill to be able well to *Mix* (that is, in effect, to *Generate*) *Colours*.

3. For *Imitation of Light* and *Colours*, 'tis well known how far *Perspective* with the Art of *Limning* and *Shadowing* have gone therein, which all tend some way to the Advance or Improvement of *Direct Vision*.

Add to all these, That *a due Application of Light to the Object* renders it Visible, if it were not so before; as appears from a dark Room illuminated; or else makes it better and more truly discernable by the Sense of *Seeing*, if before it might have been discern'd.

Hence the same *Colour*, in a divers Light, will appear different, and no *Picture* can well be discern'd or judg'd of but by its true Light. Besides, the *Limner* will assure you, that he can hardly make true Work or hit the Air of a Face exactly, unless we draw by a *North-Light*, by reason of the Steddiness of that, and the uncertainty of all other Lights whatsoever.

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Which things shew, that the *Art of duly applying Light to the Object* does very much help and improve Vision. So also does the due placing of the *Object*, as to *Height* and *Distance*. But to enumerate all things that help *Direct Vision*, would be infinite.

2. *Ex parte Organi vel Medii* Direct Vision has been improv'd by making use of a *Tube*, without Glasses, or a Man's clos'd Hand, to look thro'; which admitting into the *Eye* only the principal Rays, that come directly from the Object, do very much strengthen and clear the Sight, by excluding all the Collateral Rays, that crouding into the Eye, together with the direct ones, would confound and disturb it, partly by mixing and interfering with the Direct Rays, and partly (or rather chiefly) by too much enlightning the fund of the Eye, wherein Vision is truly (tho' then imperfectly) made.

On this is founded the Art of making *Spectacles* without Glasses; (as well as *Tubes*) which is done by putting into the Glass-holes (instead of Glasses) two short *Tubes* of between three and four Inches long (for their length is to be vary'd according to the Age or Eye of the beholder, and so also is the Diameter of the extream ends) which *Tubes* being made of *Spanish Leather* (or Past-board, or some such like matter) and black'd on the inside, are so to be plac'd, as that the visual Rays, receiv'd thro' them, may meet in one Point (or rather issue out from one Point) of the Object standing at such a due distance, as the Person may clearly and distinctly see it, or according to his length of Sight (as ABC, in the 4th Fig. *Tab.* 3.)

And

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And theſe *Spectacles* may be ſuppos'd better for preſerving the Sight, than the ordinary ones with Glaſſes, becauſe they repreſent the Object more naturally, and withal more clearly and diſtinctly to the Eye, than the other, whoſe refracted Rays being collected together with the right ones in the Glaſſes, do ſomewhat confound good Viſion, as before: Eſpecially if the viſive Power be ſtrong enough to be ſufficiently determin'd by the right Rays alone.

For I ſpeak now of preſerving a good Eye by theſe Spectacles, which holds in proportion true alſo of a bad one. Becauſe thoſe Rays (both right and refracted) being collected and brought ſo near the Eye (whether good or bad) as the Spectacles are uſually plac'd, do too much affect it, both by their own brightneſs, and alſo by the brightneſs of the Colours of the Object (when they are bright) which is brought very near alſo; whereby the Eye is dazl'd and confounded, unleſs there be a ſtrong attention and *conatus* of the Spirits, whereto the bright Rays do certainly engage them, which of neceſſity weakens Viſion, eſpecially if theſe Glaſs-ſpectacles be much us'd.

Wherefore the now deſcrib'd new Tube-ſpectacles, contributing ſo much to the help and preſervation of Sight, may well be counted an improvement of *Direct Viſion*, becauſe they convey the Rays to the Eye without any kind of refraction whatſoever. Seeing the ſame Object alſo through various holes, plac'd at certain diſtances, does ſomewhat alter Viſion; but of this perhaps more hereafter.

Now as *Direct Viſion* has thus been improved, ſo likewiſe *Direct Hearing* partly has already receiv'd, and partly may (by the Doctrine whereof

whereof we are treating, (if well cultivated) farther receive as great and notable Improvements, both *ex parte* Objecti, and *ex parte* Organi *vel* Medii.

1. As to the *Object* of Hearing, which is Sound, improvement has been and may be made, both as to the *Begetting*, and as to the *Conveying* and *Propagating* (which is a kind of *Conserving*) of Sounds.

1. As to the *Begetting* of Sounds. The Art of imitating any Sound, whether by *Speaking* (that is pronouncing) any any kind of Language, (which really is an Art, and the *Art of Speaking* perhaps one of the greatest) or by *Whistling*, or by *Singing* (which are allow'd Arts) or by *Hollowing* or *Luring* (which the Huntsman or Faulkner would have to be an Art also) or by imitating with the Mouth (or otherwise) the Voice of any Animal, as of *Quails*, *Cats*, and the like, or by *Representing* any Sound begotten by the Collision of Solid Bodies, or after any other manner; these are all *Improvements* of *Direct Hearing*, and may be improv'd.

Moreover the Skill to make all sorts of *Musical Instruments*, both Ancient and Modern, whether *Wind* Instruments or *String'd*, or of any other sort, whereof there are very many (as *Drums*, *Bells*, the *Systrum* of the *Egyptians*, and the like) that beget (and not only propagate) Sounds; the Skill of making these, I say, is an Art, that has as much improv'd *Direct Hearing*, as an Harmonious Sound exceeds a single and rude one, that is, an immusical *Tone*; which Art is yet capable of farther improvement. And I do hope, that by the Rules, which may happily be laid down concerning the *Nature*, *Preparation* and *Proportion* or *Adapting*

*dapting* of Sounds, a way may be found out, both to improve *Musical Instruments* already in use, and to invent new ones, that shall be more sweet and lushious, than any yet known. Besides that, by the same means *Instruments* may be made, that shall imitate any sound in Nature, that is not Articulate, be it of Bird, Beast, or what thing else soever.

2. The *Conveying* and *Propagating* (which is a kind of *Conserving*) of Sounds, is much help'd by *duly placing the Sonorous Body*, and also by the *Medium*.

For if the Medium be *Thin* and *Quiescent*, and the Sounding Body *plac'd conveniently*, the Sound will be easily and regularly propagated, and mightily conserv'd. I say,

1. If the *Medium be thin and Quiescent*, because it otherwise causes a *Refracted Sound*, of which afterwards. Hence in a *still Evening* or the *dead of the Night* (when the Wind ceases) a Sound is better sent out and to a greater distance than otherwise, tho' much of this may be ascrib'd to it's *Refraction* also.

2. I say, that the *Sonorous Body must be plac'd conveniently*, near a *Smooth Wall*, near *Water*, or *a Plain*, whose Surface is even.

1. Near *a Smooth Wall*, either Plain or Arch'd (Cycloidically or Elliptically, rather than otherwise, tho' a Circular or any Arch will do, but not so well.)

Hence in a Church, the nearer the Preacher stands to the Wall (and certainly 'tis much the best way to place Pulpits near the Wall) the better is he heard, especially by those who stand near the Wall also, though at a greater distance from the Pulpit; those at the remotest end of the Church, by laying their Ears some-

what

what close to the Wall, may hear him easier than those in the middle.

Hence also do arise *Whispering Places.* For the Voice being apply'd to one end of an Arch, easily rowls to the other. And indeed were the *motion* and *propagation* of Sounds but rightly understood, 'twould be no hard matter to contrive *Whispering Places* of infinite variety and use. And perhaps there could be no better or more pleasant hearing a *Consort of Musick* than at such a place as this, where the Sounds rowling along together, before they come to the Ear, must needs consolidate and imbody into one; which becomes a true composition of Sounds, and is the very Life and Soul of Consort.

2. If the Sonorous Body be plac'd near *Water* the Sound will easily be convey'd, yet mollified; as Experience teacheth us from a Ring of *Bells* near a River and a great *Gun* shot off at Sea, which differ much in the strength, and yet softness and continuance or propagation of their Sounds, from the same at Land, where the Sound is more harsh and more perishing, or much sooner decays.

3. In a *Plain* a Voice may be heard at a far greater distance than in uneven Ground.

The *Reason* of all which last nam'd *Phænomena* is the same, because the Sonorous Air meeting with little or no resistence upon a *Plane* (much less upon an Arch'd) smooth Superficies easily rowls along it, without being let or hindred in its Motion, and consequently without having its parts disfigured, and put into another kind of Revolution, than what they had at the first begetting of the Sound. Which is the true cause of its *Preservation* or *Progression*, and fails much when the Air passes over an uneven

even Surface, according to the degrees of its inequality, and somewhat also, when it passes over the plain Superficies of a Body that is hard and resisting.

Wherefore the smooth top of the Water (by reason of its yielding to the Arch'd Air, and gently rising again with a kind of resurge, like to *Elasticity*, tho' it be not so, by which resurge it quickens and hastens the motion of the Air rowling over it, and by its yielding preserves it in its Arch'd Cycloidical or Eliptical Figure) the smooth top of the Water, I say, for these reasons, and by these means, conveys a Sound more entire and to a greater distance than the plain Surface of a piece of Ground, a Wall, or any other Solid Body whatever can do.

As for the *Speaking Trumpet*, by which a Voice may be convey'd to a considerable distance, I refer its consideration to that of *Refracted Sounds* or *Refracted Audition*.

Thus much of the Improvements of Hearing, that respect its *Object* which is *Sound*.

2. The *Organ* and *Medium* are to be considered. And, 1. The *Organ*, which is the *Ear*, is helpt much by placing it near a Wall (especially at one end of an Arch, the Sound being begotten at the other) or near the Surface of Water, or of the Earth, along which the Sounds are most easily and naturally convey'd, as was before declar'd. And 'tis incredible how far a Sound made upon the Earth (by the trampling of a Troop of Horses, for Example) may be heard in a still Night, if a Man lays his Ear close to the Ground in a large Plain.



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*Otacousticks* here come in for helping the *Ear*; which may be so contriv'd (by a right understanding the *Progression of Sounds*, which is the principal thing to be known for the due regulating all such kinds of Instruments) as that the Sound might enter the Ear without any Refraction, but as now they are generally made I refer them to *Refracted Audition*.

2. As to the *Medium*, I know not how that, by any contrivance of Art, can advantage *Direct Hearing*, otherwise than I have declar'd already in the propagation or conveiance of Sounds, tho' to the Refacting or Reflecting of them it may very much conduce; of which presently.

And so I have done with the first part of my present undertaking, which is the *Comparison of Direct Vision and Audition*, as to their Improvements from Art. The rest follow. Wherefore,

II. Concerning *Refracted Vision* and its Comparison, I observe, That *Refracted Vision* is always made *Ex parte Medii*, as *Reflected* is *ex parte Objecti*. And therefore tho' *Direct Vision* may be help'd *ex parte Objecti*, *Medii vel Organi*; yet *Refracted* can be improv'd only *ex parte Medii*, and *Reflected ex parte Corporis oppositi* alone. Unless it be in a mixt or compound Vision, that is *Refracto-Reflext*, when the reflext Rays pass to the Eye through a refracting Medium, such as the Medium Internum, contain'd in the Body of the Eye always is. So that in truth all Vision is *Refracted* by an internal Refraction made in *ipso Oculo*.



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And all that I have spoken of *Vision* holds true of *Hearing* also, both *Refracted* and *Reflext*, and therefore need not be repeated.

*Refracted Vision* arises from the different *Density*, *Figure* and *Magnitude* of the Medium, which is somewhat alter'd also by the divers incidence of the visible Rays. And so it is in *Refracted Hearing*, all these Causes concur to its Production, and some others to be hereafter consider'd.

Now as any Object (a Man for example) seen through a thicken'd Air, by *Refraction* appears greater than really he is: So likewise a *Sound*, heard through the same thickned part of the *Atmosphere*, will be considerably vary'd from what it would seem to be, if heard through a thinner Medium.

And this I call a *Refracted Sound*: But what this Refraction of Sound is, and how caus'd, may hereafter be discuss'd, when the Nature, and Motion, or Progression of Sounds are well stated.

For the Improvement of *Refracted Vision* artificial Instruments have been made, by grinding or blowing Glasses into a certain Figure, and placing them at due distances, whereby the Object may be (as 'twere) enabled to send forth its Rays more vigorously, and the Visive Faculty impower'd the better to receive them. And thus also Instruminents may be contriv'd for the assisting both the *Sonorous Body*, to send forth its Sound more strongly, and the *Acoustick Faculty* to receive and discern it more easily and clearly. *For*,

1. As a fine *Glass Bubble*, fill'd with clear Water, and plac'd before a burning Candle or Lamp, does help it to dart forth its Rays to a



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prodigious length and brightness: So an *Instrument* may be invented, that apply'd to the Mouth (or any Sonorous Body) shall send forth the Voice distinctly to as prodigious a distance and loudness.

For if the *Stentoro-phonecon* (which is but a rude and unartificial Instrument) does such great feats, what might be done with one compos'd according to the Rules of Art? whose make should comply with the Laws of *Sonorous Motion* (which that does not) and therefore not so much *Refract*, as to alter and confound the *Tone* of *the Voice* and Words (as that somewhat does.)

Now of what use such an Instrument might be for speaking clearly and articulately at a distance (and that without altering the Tone of the Voice) whether it be at Sea or at Land (but especially at Sea in tempestuous Weather and in the Night) is obvious to any Man to conceive.

2. As Instruments have been invented to help the Eye, So likewise are there some, and more such there may be for the Ear.

*For*,

1. As *Spectacles* and other *Glasses* are made to help the *Purblind* and weak *Eyes*, to see at any competent distance: So there are *Otacousticks* (and better may be made) to help weak *Ears* to hear at a reasonable distance also. Which would be as great a help to the infirmity of Old Age, as the other invention of Spectacles is, and perhaps greater; forasmuch as the Hearing what's spoken is of more daily use and concern to such Men, then to be able to *read Books* or to *view Pictures*.

2. As

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2. As *Perſpective-Glaſſes* and Teleſcopes help the Eye to ſee Objects at a very great diſtance, which otherwiſe would not be diſcernable; in like manner may a ſort of *Otacouſticks* be ſo contriv'd as that they ſhall receive in *Sounds* made at a very great diſtance alſo, but with ſo much advantage, that the Ear ſhall be able to hear them, which otherwiſe would have been *inaudible*.

And theſe *Otacouſticks* in ſome reſpects would be of greater uſe than *Perſpectives*. For whereas at Land *Perſpectives* are many times render'd almoſt uſeleſs, by the interpoſition of Woods and Mountains, which hinder the Sight from reaching very far: Our *Otacouſticks* would, notwithſtanding theſe Obſtacles, take in a Sound made ſome Leagues off. Which might be of notable uſe in the time of War, for diſcovering the Enemy at a good diſtance, when he marches or lyes incamp'd behind a Mountain or Wood, or any ſuch place of ſhelter.

Yea even at Sea alſo, where *Perſpectives* are of moſt uſe, by reaſon of the plaineſs of the Surface of the Water; yet ſometimes there *Otacouſticks* may be of more benefit, when in dark hazy Weather the Air is too thick, or in Stormy Tempeſtuous Weather the Waves a riſe too high for the *Perſpective* to be made uſe of.

But whether at Sea or Land *Perſpectives* become altogether inſignificant in the Night-time (unleſs it be for viewing the Stars) which is the chief time for uſing *Otacouſticks*; as it is generally, for Souldiers to take their March, when they would ſurpriſe their Enemies.

And therefore this ſort of *Otacouſticks* have then their chief uſe, when *Perſpectives* are of no



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uſe at all; beſides that they may be imploy'd in the Day-time, as well as *Perſpectives*, whence they may (not unfitly) be term'd *the moſt uſeful Inſtrument* of the two.

3. As *Miſcoſcopes* or *Magnifying-Glaſſes* help the Eye to ſee near *Objects*, that by reaſon of their ſmallneſs were *Inviſible* before; which Objects they Magnify to a ſtrange greatneſs: So *Microphones* or *Micracouſticks*, that is Magnifying Ear Inſtruments may be contriv'd after that manner, that they ſhall render the moſt minute Sound in nature diſtinctly audible, by Magnifying it to an unconceivable loudneſs.

By the help hereof we may here the different Cries and Tones, as well as by *Microſcopes* ſee the divers Shapes and Figures of the ſmalleſt Animals.

4. As by *Polyſcopes* or *Multiplying-Glaſſes*, one thing is repreſented to the Eye as many, whether in the ſame or different Shapes (for ſo Multiplying-glaſſes may be contriv'd:) So by a *Polyphone* or *Polyacouſtick* well order'd one *Sound* may be heard as many, either of the ſame or a different Note. Inſomuch, that who uſes this Inſtrument, he ſhall, at the Sound of a ſingle Viol, ſeem to hear a whole Confort and all true Harmony. By which means this Inſtrument has much the advantage of the *Polyſcope*.

And thus much may ſuffice for compairing the Improvenments made upon *Refracted Seeing and Hearing*; I call it *Refracted Hearing*, becauſe made throngh a *Medium*, viz. thick Air or an Inſtrument, through which the Sound paſſing is broken or refracted.

III. *Reflected*

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III. *Reflected Vision* has been improv'd by the Invention of *Looking-glasses* and *Polish'd Metals*, whether *Plane*, *Concave*, or *Convex*; and these two last, either *Spherical*, *Oval*, *Cylindrical*, *Conical*, *Hyperbolical*, or of several other shapes; all which cause a different Reflection, and vary the *Phanomena*.

Thus also *Reflex'd Audition*, made by *Ecchoes*, may be improv'd, by contriving several sorts of *Artificial Ecchoes*; as 'tis no hard matter to do in almost any place.

For (speaking in the general) *Any Sound, falling directly or obliquely upon any dense Body, of a smooth (whether Plane or Arch'd) Superficies, is beat back again and reflected, or does eccho more or less.*

I say (1.) *falling directly or obliquely*; because, if the Sound be sent out and propagated *parallel* to the Surface of the *Dense Body*, or be made so *far off* and so *weak*, that it cannot reach it, there will be no reflection of Sound, no *Eccho*.

I say (2.) *upon a Body of a smooth Superficies*; because if the Surface of the *Corpus Obstans* be uneven, the Air by reverberation will be put out of its regular Motion, and the Sound thereby broken and extinguish'd: So that tho' in this case also the Air be beaten back again, yet Sound is not reflected, nor is there any Eccho.

I say (3) *it does eccho more or less*, to shew, that when all things are, as is before describ'd, there is still an Ecchoing, though it be not always heard; either because the *direct Sound* is too weak to be beaten quite back again to him that made it; or that it does return home to him, but so weak, that without the help of a good *Otacoustick* it cannot be discern'd; or that

he stands in a wrong place to receive the reflected Sound, which passes over his head, under his Feet, or to one side of him; which therefore may be heard by a Man standing in that place, where the reflected Sound will come, provided no interpos'd Body does intercept it; but not by him, that first made it.

I shall further make out the comparison 'twixt *Reflex'd Vision* and *Audition*, by these following *Propositions*.

1. As a *Plane Speculum* reflects the *Object* in its due *Dimensions* and *Colours*; allowing for their difference of appearance according to their distance: So a *Plane Corpus Obstans* reflects the *Sound* back in its due *Tone* and *Loudness*; if allowance be likewise made for the proportionable decrease of the Sound according to its distance.

2. As a *Convex Speculum* reflects the Object *less*, but somewhat *brighter* or clearer: So a *Convex Corpus Obstans* repels the Sound (insensibly) *smaller*, but somewhat *quicker* (though *weaker*) than otherwise it would be.

3. As a *Concave Speculum* reflects the Object *bigger*, more *obscure* and *Inverted*: So a *Concave Corpus Obstans* ecchoes back the Sound (insensibly) *bigger*, *slower* (though *stronger*) and also *inverted*; but never according to the order of Words. Nor do I think it possible for the Art of Man to contrive a *Single Echo*, that shall invert the Sound and repeat backwards; because then the Words last spoken, that is, which do last occurr to the *Corpus Obstans*, must first be repell'd; which cannot be: For where in the meantime should the first Words hang, and be conceal'd, or lie dormant? Or how, after such a pause, be revivi'd and animated again into

into Motion? Yet in complicated or *Compound Ecchoes*, where many receive from one another, I know not whether something that way may not be done.

From the determinate *Concavity* or *Archedness* of these reflecting Bodies, it comes to pass, that some of them, from a certain distance or posiure, will eccho back but one determinate Note, and from no other place will they reverberate any; because of the undue Position of the sounding Body. Such an one (as I remember) is the Vault in *Merton* College in *Oxford*.

4. As a *Speculum* takes in and reflects more of its Object, when plac'd at a great distance from it, than when nearer; because it reflects according to the apparent Magnitude of the Body at such a distance, which is less: So also the *Ecchoing Body*, being removed farther off, reflects more of the Sound, than when nearer. And this is the reason, why some Ecchoes repeat but one Syllable, some one Word, and some many.

5. As *Specula's* may be so plac'd, that reflecting one upon or into the other, either directly or obliquely, one Object shall appear many; as in Sir *Samuel Moreland's* Glass-room: After the same manner *Ecchoing Bodies* may be so contrived and plac'd, as that reflecting the Sound from one to the other, either directly and mutually, or obliquely and by Succession, out of one Sound shall many Ecchoes be begotten; which in the first case will be all together, and somewhat involv'd or swallow'd up of each other, and thereby confus'd (as a Face in Looking-glasses obverted) in the other they will be distinct, separate, and succeeding one another; as most *multiple Ecchoes* do.

Moreover

Moreover a *Multiple Eccho* may be made, by so placing the *Ecchoing Bodies*, at unequal distances, that they reflect all one way, and not one on the other; by which means a manifold successive Sound will be heard (not without astonishment) one clap of the hands like many, one ha like a laughter, one single word like many of the same tone and accent, and so one Viol like many of the same kind imitating each other.

Furthermore, as *Specula's* may be so order'd, that by Reflection they shall make one single thing appear many different things; as one single Man to seem many Men, differing as to shape and Complexion (or a company of Men) which I think Sir *Samuel Moreland*'s Contrivance does not: So may *Ecchoing Bodies* also be order'd, that from any one Sound given, they shall produce many Ecchoes, different both as to their *Tone* and *Intension*. (The ground whereof has elsewhere been laid down in a Treatise concerning the *Sympathy of Lute-strings*.)

By this means a *Musical Room* may be so contriv'd, that not only one Instrument, play'd on in it shall seem many of the same *sort* and *size*; but even a Consort of (somewhat) different ones; only by placing certain *Ecchoing Bodies* so, as that any Note (play'd) shall be return'd by them in 3ds, 5ths, and 8ths, which is possible to be done otherwise than was mention'd before in *Refracted Audition*.

I have now done with my *Comparison* of the two Noblest *Senses* and *Sciences*, as to their *Improvements*; wherein I have been thus large, that I might give you a little prospect into the *Excellency* and *Usefulness* of *Acaustricks*; and that thereby I might excite all that hear me, to bend their

their Thoughts towards the making of Experiments for the compleating this (yet very imperfect, though noble) Science; a *Specimen* whereof I will give you in three *Problems*, and then present you with the *Semiplane* of *an Acoustick or Phonical Sphere*, as an Attempt to explicate the great *Principle* in this Science, which is *The Progression of Sounds.*

*The Problems are these:*

1. *Sonum intendere quousque velis*; or, *Datum sonum ad datum gradum intendere.*
2. *Sonum extendere quousque velis*; or, *Datum sonum ad datam distantiam extendere seu propagare.*
3. *Sonum transire ab extremo ad extremum & non per Medium.*

1. The first is, *To make the least Sound* (by the help of Instruments) *as loud as the greatest*; a whisper to become as loud as the shot of a Canon.

By the help of this *Problem*, the most minute Sounds in Nature may be clearly and distinctly heard.

2. The second is, *To propagate any* (the least) *Sound to the greatest distance.*

By the help hereof any Sound may be convey'd to any, and therefore heard at any distance, (I must add, within a certain, though very large Sphere.)

Moreover, by this means, a *Weather-cock* may be so contriv'd, as that with an ordinary blast of Wind it shall cry (or whistle) loud enough to be heard many Leagues: Which happily may be found of some use, not only for *Pi-*

*lots*

*lots* in mighty tempeſtuous Weather, when *light Houſes* are render'd almoſt uſeleſs; but alſo for the meaſuring the ſtrength of Winds, if allowance be made for their different moiſture. For I conceive, that the more dry any Wind is, the louder it will whiſtle *cæteris paribus*; I ſay, *cæteris paribus*, becauſe, beſides the ſtrength and and dryneſs of Winds or Breath, there are a great many other things (hereafter to be conſider'd) that concur to the increaſe or magnifying of Sounds, begotten by them in an Inſtrument expoſed to their violence, or blown into.

3. The third *Problem* is, *That a Sound may be convey'd from one extreme to the other* (or from one diſtant place to another) *ſo as not to be heard in the middle.*

By the help of this *Problem* a Man may talk to his Friend at a very conſiderable diſtance, ſo that thoſe in the middle ſpace ſhall hear nothing of what paſſed betwixt them.

## FIG. V. TAB. III.

### *Semiplanum Sphæræ Phonicæ ſeu Acouſticæ.*

You are to conceive that (rude) *Semiplane*, as parallel to the *Horizon*: For if it be perpendicular thereunto, I ſuppoſe the upper extremity will be no longer *Circular*, but *Hyperbolical*, and the lower part of it ſuited to a greater Circle of the Earth. So that the whole *Phonical* Sphere (if I may ſo call it) will be a ſolid *Hyperbola*, ſtanding upon a *Concave Spherical* Baſe. I ſpeak this concerning *Sounds* made (as uſually they are) nigh the Earth,

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Earth, and whoſe Sonorous *Medium* has a free paſſage every way. For if they are generated high in the Air, or directed one way, the caſe will be different; which is partly deſign'd in the inequality of that draught.

A

## *A Discourse concerning the Modern* Theory *of* Generation, *by Dr.* George Garden *of* Aberdeen, *being part of a Letter to Dr.* William Musgrave, *L. L. D. Reg. Soc. S. and by him communicated to the Royal Society.*

THE Subject I pitch upon, is that of the Formation of Animals. You know how wide and unsatisfying Mens Conjectures were upon this Head, until this Age, in which first the deservedly Famous Dr. *Harvey* discovered the proper place of the Formation of the Chick in the *Cicatricula* of the Egg, and the Formation of the Parts so far as was discernable by the naked Eye; and after him *Malpighius*, by the help of exact Glasses, observed the first Rudiments of it there, both before and after Incubation: And *R. de Graef*, and others, having upon many Observations concluded, that the *Testes Fœminei* were the Ovaries of Females, and consequently that all Animals were *ex ovo*; they began from hence to infer, that the Rudiments of each Animal were originally in the respective Females, and that the Male contributed only to give a new Ferment to the Mass of the Blood and Spirits, by which means a spirituous Liquor (which the Blood in its ordinary Ferment could not produce) did insinuate its self into the

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the same Ducts and Pores of the Rudiments of those Animals, which were in greatest forwardness in the Ovary, and so extend, and enlarge all their Parts, and at last bring them to perfection, as Mr. *Perrault* does ingeniously discourse in the third Part of his *Essais de Physique*; till now at last *Leowenhoek* has discovered an infinite number of *Animalcula in semine marium* of all kinds, which has made him condemn the former Opinions about the Propagation of all Animals *ex Ovo*.

Now upon comparing the Observations and Discoveries which have been made with one another, these three things seem to me very probable. 1. That Animals are *ex Animalculo*. 2. That these Animalcles are originally *in semine Marium & non in Fœminis*. 3. That they can never come forward, nor be formed into Animals of the respective kind, without the *Ova in Fœminis*.

The first of these seems probable from these three Observations. 1. That some such thing has been so often observed by *Malpighius*, in the *Cicatricula* of an Egg before Incubation, as the Rudiments of an Animal in the shape of a Tadpole, as may be seen in his first, and in his repeated Observations *de formatione Pulli in Ovo*. 2. The sudden appearance and displaying of all the Parts after Incubation, makes it probable, that they are not then actually formed out of a fluid, but that the *Stamina* of them have been formerly there existent, and are now expanded. The first Part of the Chick which is discovered with the naked Eye, is, you know, the *Punctum saliens*, and that not till three days and nights of Incubation be past; and then, on the

the fifth day, the Rudiments of the Head and Body do appear. This made Dr. *Harvey* conclude, that the Blood had a being before any other Part of the Body; and that from it, all the Organs of the *Fœtus* were both form'd and nourished: But by *Malpighius*'s Observations we find that the Parts are then only so far extended, as to be made visible to the naked Eye, and that they were actually existent before, and discernable by Glasses. After an Incubation of thirty hours, are to be seen the Head, the Eyes, and the *Carina*, with the *Vertebræ*, distinct, and the Heart. After forty hours its Pulse is visible, and all the other Parts more distinct, which cannot be discerned by the naked Eye before the beginning of the fifth day; from whence it seems probable, that even the so early discovery of those Parts of the *Fœtus* by the Microscope, is not the discerning of Parts newly formed, but only more dilated and extended by receiving of Nutriment from the *Colliquamentum*; so that they seem all to have been actually existent before the Incubation of the Hen. And what *Swammerdam* has discovered in the transformation of Insects, gives no small light to this; whilst he makes appear in the Explanation of the 13th Table of the General History of Insects, that in those large *Eruca's* which feed upon Cabbage, if they be taken about the time they retire to be transform'd into *Aurelia's*, and plung'd often in warm Water to make a Rupture of the outer Skin, you will discern thro' the transparency of their second Membrane, all the Parts of the Butterfly, the Trunk, Wings, Feelers, *&c.* folded up. But that after the *Eruca* is chang'd into an *Aurelia*, none of these Parts can be discerned, they are so drencht

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drencht with moiſture, tho' they be there actually form'd. Another Conſideration is from the Analogy, which we may ſuppoſe between Plants and Animals. All Vegetables we ſee do proceed *ex Plantula*, the Seeds of Vegetables being nothing elſe but little Plants of the ſame kind folded up in Coats and Membranes; and from hence we may probably conjecture, that ſo curiouſly an organized Creature as an Animal, is not the ſudden Product of a Fluid or *Colliquamentum*, but does much rather proceed from an Animalcle of the ſame kind, and has all its little Members folded up according to their ſeveral Joints and Plicatures, which are afterwards enlarged and diſtended, as we ſee in Plants. Now tho' this Conſideration alone may ſeem not to bear much weight; yet being join'd to the two former they do mutually ſtrengthen each other. And indeed all the Laws of Motion which are as yet diſcovered, can give but a very lame account of the forming of a Plant or Animal. We ſee how wretchedly *Des Cartes* came off when he began to apply them to this Subject; they are form'd by Laws yet unknown to Mankind; and it ſeems moſt probable, that the *Stamina* of all the Plants and Animals that have been, or ever ſhall be in the World, have been formed, *ab Origine Mundi*, by the Almighty Creator within the firſt of each reſpective kind. And he who conſiders the Nature of Viſion, that it does not give us the true magnitude, but the proportion of things; and that what ſeems to our naked Eye but a Point, may truly be made up of as many Parts as ſeem to us to be in the whole viſible World, will not think this an abſurd or impoſſible thing.



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But the second thing which later Discoveries have made probable, is, that these Animalcules are originally *in Semine Marium & non in Fœminis.* And this I collect from these Considerations: 1. That there are innumerable *Animalcula* discovered *in Semine Masculo omnium Animalium.* Mr. *Leewenhoeck* has made this so evident by so many Observations, that I do not in the least question the truth of the thing. The reason of their multitude, and some of the difficulties which arise thereupon, he has cleared to very good purpose, so that I shall not repeat them. 2. The observing the Rudiments of the *Fœtus* in Eggs, which have been fecundated by the Male, and the seeing no such thing in those which are not fecundated, as appears from *Malpighius* his Observations, make it very probable that these Rudiments proceed originally from the Male, and not from the Female. 3. The resemblance between the Rudiments of of the *Fœtus in Ovo*, both before and after Incubation, and the *Animalcule*, makes it very probable that they are one and the same. The same Shape and Figure which Mr. *Leewenhoeck* gives us of the *Animalcule*, *Malpighius* likewise gives of the Rudiments of the *Fœtus*, both before and after Incubation; yea, and even the *Fœtus's* of Animals do appear so at first to the naked Eye, so that Dr. *Harvey* does acknowledge that all Animals, even the most perfect, are begotten of a Worm, *De Gen. Anim. Ex.* 18. 4. This gives a rational account of many *Fœtus's* at one Birth, especially that of the Countess of *Holland*, and how at least a whole Cluster of Eggs in a Hen are fecundated by one Coition of the Male. 5. This gives a new light, as it were, to the first Prophecy concerning the

*Messiah*,

*Messiah*, that the Seed of the Woman shall bruise the Head of the Serpent, all the rest of Mankind being thus most properly and truly the Seed of the Man. 6. The Analogy I have already mentioned, which we may rationally suppose between the manner of the propagation of Plants and Animals, does likewise make this probable. Every Herb and Tree bears its Seed after its kind; which Seed is nothing else but a little Plant of the same kind, which being thrown into the Earth, as into its *Uterus*, spreads forth its Roots and receives its nourishment, but has its form within its self, and we may rationally conjecture some such Analogy in the Propagation of Animals.

The third Particular which later Discoveries make probable, is, that Animals cannot be form'd of these *Animalcula* without the *Ova in fœminis*, which are necessary for supplying of them with proper Nutriment: And this these Considerations seem to evince. 1. It is probable that an Animalcule cannot come forward, if it do not fall into a proper *Nidus*. This we see is the *Cicatricula* in Eggs; and tho' a Million of them should fall into an Egg, none of them would come forward, but what were in the Center of the *Cicatricula*; and perhaps the *Nidus* necessary for their formation is so proportion'd to their bulk, that it can hardly contain more than one Animalcule; and this may be the reason why there are so few Monsters. This we see is absolutely necessary in *Oviparis*; and the only difference which seems to be between them and the *Vivipara*, in this matter, is in this, that in the latter the *Ova* are properly nothing more but the *Cicatricula*, with its *Colliquamentum*, so that the *Fœtus* must spread forth

its Roots into the *Uterus* to receive its nouriſhment; But the Eggs in *Oviparis* may be properly term'd an *Uterus*, in relation to the *Fœtus*; for they contain not only the *Cicatricula*, with its *Amnion* and the *Colliquamentum*, which is the the immediate nouriſhment of the *Fœtus*, but alſo the materials which are to be converted into that *Colliquamentum*; ſo that the *Fœtus* ſpreads forth its Roots no farther than into the white and yolk of the Egg, from whence it derives all its nouriſhment. Now that an Animalcule cannot come forward without ſome ſuch proper *Nidus*, Mr. *Leewenhoeck* will not readily deny; for if there were nothing needful, but their being thrown into the *Uterus*, I do not ſee why many hundreds of them ſhould not come forward at once; for as to what Mr. *Leewenhoeck* ſays, that one of them would be-dwarf and choak the reſt; this might fall out in proceſs of time: But at firſt I do not ſee why many of them ſhould not grow together, whilſt ſcatter'd in ſo large a Field (and yet no ſuch thing is obſerved) if there were not an abſolute neceſſity of a *Cicatricula* for their growth and thriving. Now, 2. That this *Cicatricula* is not originally in *Utero*, ſeems evident from the frequent Conceptions which have been found *extra Uterum*: Such as the Child which continued Twenty ſix years in the Woman of *Tholouſe*'s Belly, mentioned *Numb.* 139. of the *Phil. Tranſ.* And the little *Fœtus* found in the *Abdomen de St. Mere*, together with the Teſticle torn and and full of clotted Blood, recorded *Numb.* 150. both taken out of the Journals *des Scavans*: Such alſo ſeem to be the *Fœtus* in the *Abdomen* of the Woman of *Copenhagen*, mentioned in the *Nouvelles des Lettres*, for *Sept.* 85. *pag.* 996. all



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the Members of which were easily to be felt thro' the Skin of the Belly, and which she had carried in her Belly for four Years; and the seven Years Gravidation, related by Dr. *Cole*, *Numb.* 172. of the *Transact.* That these two were undoubtedly *extra Uterum*, is uncertain, because the last was not opened after her death, and the former may be yet still alive. Now granting once the necessity of a proper *Nidus*, for the formation of an Animalcle into the Animal of its respective kind; these Observations make it probable, that the *Testes* are the *Ovaria* appropriated for this use; for tho' the Animalcles coming thither in such Cases may seem to be extraordinary, and that usually the Impregnation is *in Utero*; yet it may be collected from hence, that the *Cicatriculæ* or *Ova* to be impregnated, are in *Testibus fœmineis*; for if it were not so, the accidental coming of Animalcles thither could not make them come forward more than in any other part of the Body, since they cannot be formed and nourished without a proper *Nidus*. But 3. It is acknowledg'd by all, that the *Fœtus in Utero*, for some considerable time after Conception, has no connexion with the Womb, that it sits wholly loose to it, and is perfectly a little round Egg with the *Fœtus* in the midst, which sends forth its Umbilical Vessels by degrees, and at last lays hold on the *Uterus*. Now from hence it seems evident, that the *Cicatricula*, which is the Fountain of the Animalcles nourishment, does not sprout from the *Uterus*, but has its *Origin* elsewhere, and falls in thither as into a fit Soil, from whence it may draw Nutriment for the growth of the *Fœtus*; else it cannot be easily imagin'd, how it should not have an immediate



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Connexion with the *Uterus* from the time of Conception. If you join all these three Considerations together, *viz.* that an Animalcule cannot come forward without a proper *Nidus* or *Cicatricula*; that there have been frequent *Fœtus's extra Uterum*; and that they have no *Adhæsion* to the *Uterus*, for a considerable time after Conception, they seem to make it evident, that Animals cannot be form'd *ex Animalculis* without the *Ova in Fœminis*. To all these I shall subjoin the Proposal of an *Experimentum Crucis*, which may seem to determine, whether the *Testes Fœmineæ* be truly the *Ovaria*, *viz.* Open the *Abdomen* of the Females of some kinds, and cut our these Testicles, and this will determine, whether they be absolutely necessary for the formation of Animals.

There are some Difficulties proposed against this Conjecture, which I think may be easily resolved. Some object the distance between the *Tubæ* or *Cornua Uteri*, and the Testicles; but to this is opposed by *Swammerden*, and others, the like distance between the *Infundibulum*, in Hens and Frogs, and the Ovary; and yet it cannot be denied that the Eggs are transmitted thro' this into the *Uterus*: and besides *R. de Graef*, and others, have by repeated Observations found that the *Cornua Uteri* do at certain times after Conception, embrace the *Testes* on both sides the *Uterus*. They object in the second place the great disproportion between the pretended Eggs in the Ovary, and the Aperture of the *Tubæ* or *Cornua Uteri*, the former being a great deal bigger than the latter: But both *R. de Graef* and *Malpighius* have clear'd that Matter, by making appear, that these Bladders in the Ovary are not the *Ova*, but serve to form the *Glandules* within

within which the *Ova* are formed, which break through a small *Papilla* opening in the *Glandule*, which bears a proportion to the Aperture of the Tube. They object 3. The difficulty to conceive how these Eggs should be impregnated *per semen Maris*, both because there is no Connexion between the *Tubæ* and the Ovary for its transmission, and for that Dr. *Harvey* could never discover any thing of it in *Utero*. As to the last, Mr. *Leewenhoeck* has cleared that difficulty, by the discovery of innumerable *Animalcula Seminis Maris in Cornubus Uteri*, and those living a considerable time after Coition. *Numb.* 174. of the *Transact*. And as to the former, we may either suppose that there is such an Inflation of the *Tubæ* or *Cornua uteri tempore Coitionis*, as makes them embrace the *Ovaria*, and such an approach of the *Uterus* and its *Cornua*, as that it may easily transmit the Seed into the Ovary; or else, that the *Ova* are impregnated by the Animalcles after they descend into the *Uterus*, and not in the Ovary; the former seems probable for this reason, that at least a whole Cluster of Eggs in a Hen will be fecundated by one Tread of the Cock: Now this Fecundation seems to be in the Vitellary, and not in the *Uterus*, as the Eggs pass along from day to day; for it can hardly be supposed that the Animalcles should subsist so long, being scattered loosely in the *Uterus*, as to wait there for many days for the Fecundation of the Eggs as they pass along. The latter conjecture has this to strengthen it, that the Animalcles are found to live a considerable time in the *Uterus*; and that if they should impregnate the *Ova* in the Ovary its self, the *Fœtus* would increase so fast, that the *Ova* could not pass thro' the *Tuba Uteri*,

but would either burst the Ovary, or fall down into the Abdomen from the Orifices of the *Tubæ*; and that from hence proceed those extraordinary Conceptions in *Abdomine extra Uterum.* But, 4. Mr. *Leewenhoeck*, *Numb.* 147. of the *Transact.* to weaken the third Consideration about the Conceptions, being like unto an *Ovum* in the Womb, proposes a Parallel between these Animalcules and Insects; and insinuates, that as the latter cast their Skins and appear of another Shape, so the other which at first seem like Tadpoles, may cast their outer Skin and and then be round, and that this may be the occasion of the round Figure of the Conception in the Womb. To this it may be replied, that according to Mr. *Leewenhoeck*'s own Sentiment, the Animalcles cannot come forward, if they do not find the *Punctum* or proper place for their Nourishment, to which it seems they must have some *Adhæsion.* Now the Conception in *Viviparis* is not fastned unto the Womb for many days, nor does adhere to any point of it; so that it seems this roundish Body is not the Animalcle thus chang'd after having cast an outer Skin, but is rather the *Cicatricula* or little Egg, into which the Animalcle has entred as its *Punctum* or place of Nourishment; else I do not see why they should not be adhering to the Womb from the first Conception, or why (as I have said) many hundreds of them are not conceived and formed together, *&c.*

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## *A short Discourse concerning Concoction: Read at a Meeting of the Royal Society*, May 1699, *by* Clopton Havers, *M. D. Fellow of the Royal Society.*

THE manner in which the Digestion of the Aliment is performed, is a thing not very easie to be understood and explain'd. However, it has not escap'd the Conjectures of some Philosophical Men, who having curiously observ'd the *Phænomena* of Nature, and enquired into their Causes, have, amongst other things, endeavour'd to account for this. But their Sentiments about it have been various, and the Hypothesis, by which they have studied to explain it, very different. Some have thought the Concoction of the Food to be a kind of Elixation; and that the grosser and more solid Parts being, as it were, boil'd in the Liquid by the Heat of the Stomach, and the Parts adjacent to it, as the Liver, Spleen, and Omentum, are by a long and continued Elixation first render'd more tender, and then colliquated, and dissolved into minuter Particles, so as to mix more equally with the fluid, and with that to make one Pulpament, or chylous Mass. And *Hippocrates*, tho' he does not plainly call it an Elixation, yet seems to attribute the Concoction of the Food to the Heat of the Stomach, as the Cause of it; *Sect. 4. Libro de Salubri victus ratione.*

*ratione.* So where he takes notice of the voiding of such Fœces, as appear to be like the Food that has been eaten, he adds, *Constat enim, sane ventriculum, ciborum copiam, ut concoquat, calefacere non posse.* And there are other Passages in the same Book, from which we may conclude, that he suppos'd the Heat of the Stomach to be the great Cause of the Digestion of the Food.

There are others that make the Stomach it self to be the great Instrument of Digestion, but in a different manner: And they suppose it to be perform'd by an Attrition, as if the Stomach, by those repeated motions, which are the necessary Effects of Respiration, when it is distended by the Aliment, did both rub or grind off some minuter Particles from the grosser Parts, and by continually agitating the Mass of Food, make those Parts, which are not contiguous to the Stomach, strike one against another, and break one another in pieces, until they are all attenuated. It is evident enough, that the sides of the Stomach do in Expiration press upon the Contenta, so as to oblige, at least some Parts of them, every time the Muscles of the Abdomen are contracted, to move and shift their places. So in Inspiration, when the Diaphragm and Liver press upon the upper part of the Stomach, the Aliment must be moved again. So that by these reciprocal motions, that part of the Food which is contiguous to the Stomach, and moves in a Line parallel to it, must rub against it; and all the other Parts being moved by such a Compression, as gives them a different Tendency, it is certain they must be continually striking one against another. And for Bread, and such things as are made of Flour,

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er, that will be soften'd and dissolv'd with any common Liquid, that Agitation of the Stomach which moves them in Respiration, might seem sufficient to break and dissolve them, when they are sufficiently moisten'd with a Fluid. Yet this cannot be thought enough to break and digest Flesh-meat, Fruits, or any other thing that will not be softned and dissolv'd in Water, or some such Liquid. But altho' this Motion of the Aliment, caused by Respiration, does not actually digest it, yet it has a great and necessary Use in Concoction, and makes all the grosser Parts, as they are attenuated, mix equally with the Fluid.

Some think that the Bilious Juice; others, that the Spirits are chiefly concern'd in this Affair. *Galen*, in his Book *de Naturalibus Facultatibus*, makes it to be the Effect, not of one, but of several Causes; as a pituitous Juice in the Stomach, the Bile, *&c.* which appears from what he has said, and the Translator thus render'd: '*Verum quanto ii (cibi) qui mansi sunt, iis, qui* '*inhæserunt, magis sunt alterati; tanto etiam his* '*magis ii, qui devorati sunt. Siquidem incompa-* '*rabilis erit horum alterationis excessus, si & quæ* '*in ventre est Pituita & Bilis, & Spiritus, & Ca-* '*lor, & tota Ventris substantia, æstimentur.*

Some there are that will have the Food to be dissolv'd by a Menstruum, which is supply'd from the Glands of the Stomach, or some other way; But those that do so far agree in the General, as to think Concoction is perform'd by a Dissolvent, do differ in their Notions of the Nature of the Menstruum: For there are some that suppose it to be an Acid, which does erode the grosser Parts of the Food, and dissolves them in the same manner as Vinegar, Spirit of Vitriol,

triol, or any such-like Acid, will dissolve even so solid a Body as Iron. And it cannot be deny'd, but that Oil of Vitriol will dissolve Flesh-meat, and reduce it to a Pulp; but it is not to be suppos'd, that the Fibres of the Stomach can admit any such strong and corroding Acid, without something to correct it, but it must be injur'd in its Tone, and labour under great and extraordinary Pains. Neither does such a Menstruum, tho' it will digest some things, seem capable of dissolving so great a Variety of Things as we eat, especially when a great many of them are of a contrary Nature. Some will have the Menstruum to be a *nitro-aerius* Spirit, that is, quick, and very penetrating, and included in its proper Vehicle; which, being in its own Nature apt to penetrate the Mass of the Aliment, does diffuse it self through the Whole, and breaking the Vinculum of the more solid Parts, does dissolve their Compages. By others, it is thought to be some saline Juice in the Stomach, by which the Parts of the Aliment are divided and dissolved, and those which are fit for Nourishment, are volatiliz'd.

Lastly, There are some others who reject the Opinions I have already mention'd, and suppose the Digestion of the Food to be perform'd by the Benefit of a Ferment; which, when it is mix'd with the Aliment, excites in the Mass an intestine motion; and the different and contrary motions or tendency of the Parts making some kind of Collision, gradually break off Particles from the grosser, and more solid Parts, 'till they are so attenuated as to be apt to mix more equally with the Fluid, and with them to make one soft or chylous Substance. But yet there is not amongst them an universal Consent,

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sent, either about the Nature of this Ferment, or the manner how it is supply'd. For first, some think it to be the Remains of the Food that was last digested; which having lain some time in the Stomach, after the rest is carried down into the Intestines, contracts an Acid, or some other Quality, and is so alter'd as to partake of the Nature of a Leaven. And this Leaven being a part of the Food, which has been already digested, is so soft and liquid as to be capable of mixing with the Aliment, which is next taken into the Stomach; and being agitated with it by the repeated Pressures of the Diaphragm, Liver, and Abdominal Muscles upon the Stomach in Respiration, does diffuse it self through the whole Mass; and being mixed with it, like Leaven, or Yest added to new Wort, *&c.* puts it into a State of Fermentation; and by this Fermentation, or the Expansion of the Ferment, and the more tenuious Parts, which are first put into motion by it, those which are more solid, and with which they are intermix'd, are rent, and divided, and so attenuated, as to become a soft and pulpous matter. And altho' the greatest part of the Food, that is thus broken and concocted, is by the Contraction of the Fibres of the Stomach press'd into the Duodenum; yet they do not contract themselves so as to force out all the Aliment, but leave between the *Ruga* or Folds, on the inside of the Stomach, a sufficient Quantity to be a Leaven to the next Meal; and so from time to time.

Some have a Notion, That this Ferment, or Principle of Fermentation, is in the Aliment it self; which being a Congeries of Matter, consisting of various Parts of a different Nature,

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is no ſooner encloſed in the Stomach, and digeſted in the Heat of that, and the adjacent Parts, but the more ſpirituous and ſubtil Particles are put into motion both from that Warmth, and the difference of their Natures, and enter upon a Fermentation. And ſo by their inteſtine Commotion, and the Violence they offer to thoſe Parts which oppoſe the tendency of any of them, they break and diſſolve what is more ſolid.

Again: Some ſuppoſe, that this Ferment is ſupply'd from the Glands of the Stomach.

And Laſtly, Others, and perhaps with much better Reaſon, contend for the Saliva, and make that to be the Ferment, which ſerves principally for the Digeſtion of the Food; which in Maſtication being mix'd with our Aliment, is with that carried down into the Stomach, where the Parts of it being put into motion by a kindly and agreeable Heat, they do ferment with, and exagitate firſt thoſe Parts of the Food which are moſt apt to ferment with it, and then both conſpire to break and diſſolve the groſſer and more ſtubborn Parts. And *Galen*, in the Book I have before-mentioned, plainly allows that the *Saliva* is concerned in the buſineſs of Concoction, tho' he ſuppoſes the Alteration, which is produc'd by this Juice, to be made in the Mouth, as appears from theſe Words: *Quæ (alteratio) in ore agitur mutat quidem id (nutrimentum) in alteram ſpeciem manifeſte, non tamen ad perfectionem tranſmutat ---- Qui manſi ſunt cibi primum quidem hac Pituita (oris) inbuuntur, & cum ea miſcentur ---- Itaque majorem mutationem conſecuti ſunt, quam ii, qui in vacuis dentium intervallis fuere impacti.*



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Now I have given this short Account of the various Opinions of some Ingenious Men, concerning the manner how Concoction is perform'd; I come now to propose my own Hypothesis, by which I shall endeavour to explain it.

In order to the more easie and effectual Digestion of the Food, Nature has appointed some Parts for the breaking our Aliment, and reducing whatever is gross into smaller Parts, before it is put upon Digestion: Others to supply the Ferment, by which it is to be dissolv'd and concocted, and which, before it comes to be included in the Stomach, does moisten, and make it more soft, that it may more easily be penetrated and broken by those Parts which serve to divide every Morsel into smaller Pieces, and prevents the Inconvenience and Trouble which would arise from the Nourishment sticking about or between them, when it is dry or viscous.

For the breaking of that part of our Food, which is not liquid, Nature has furnish'd us with Teeth, and those of two sorts: For some are ordain'd to divide and break off smaller Morsels from a larger Mass; others are made for the grinding those Morsels into much smaller parts. The Teeth, which serve to break off Pieces of a convenient Magnitude from a larger Mass, are of two sorts accommodated to the Nature of the Substance which we eat. These are the *Incisores*, and the *Dentes Canini*. If the Substance, which we have to eat, be not hard, but more easily penetrated and divided, then the *Incisores* are capable of making an Impression upon it, and fix'd firmly enough in the Jaws

Jaws to break off that part which they take hold of. But if it be more ſolid, and not eaſily penetrated, nor any Piece without difficulty to be ſeparated from that Body, whereof it is a part; then we apply the *Dentes Canini*, or Eye-Teeth to it, which are not ſpread, nor have ſuch an edge as the *Inciſores*, but are ſharp and pointed like an Awl, and ſo do more readily penetrate a Subſtance that is hard, and which the *Inciſores* can ſcarcely make any Impreſſion upon. And as the Parts of a more ſolid Body are commonly with more difficulty ſeparated, and there muſt be a greater ſtreſs put upon thoſe Teeth which pull it into pieces; ſo theſe Teeth are much more firmly fixed in the Jaws than the *Inciſores*, tho' they have but one ſingle Root. Beſides, the Poſition of all theſe Teeth is accommodated to their uſe, as being planted oppoſite to the Aperture of the Mouth; ſo that they may be conveniently apply'd to the Subſtance which we have to eat, before it is broken, and when it is too large to be admitted within the Mouth.

The Teeth which do by a Compreſſion and Attrition reduce the little Morſels to ſmaller Parts, are from the manner in which they break the Aliment, called *Dentes Molares*, becauſe they do, like ſo many Mill-ſtones, grind the Food between them. And that they might be render'd fit for this purpoſe, they are made broad at that Extremity, which ſtands out of the Gums, by which means they retain ſome Quantity of the Food between them every time the lower Jaw is pulled up and forc'd againſt the *Maxilla ſuperior*. And as they are broad, ſo they are formed with Inequalities and Protuberances; and by the motion of the lower Jaw,

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from one side towards the other, they grind what they have between them into pieces. The Position of these Teeth too is as convenient as that of the *Incisores*, and the *Dentes Canini*: For being design'd to break those pieces of our solid Food, which are taken into the Mouth, and these pieces, when they are compress'd, and moved by the *Dentes Molares*, being apt to fly out of the Mouth, if there were no Contrivance to prevent it, they are placed beyond the Aperture of the Mouth, and opposite to the Cheeks, which keep the Food within that Cavity, and not only so, but press it in between the *Dentes Molares* on one side, as the Tongue does on the other, until they have sufficiently broken and divided it.

At the same time, whilst the *Dentes Molares* are breaking the Food, there flows into the Mouth a salival Juice which mixes with it, and not only serves to moisten it, and to render it more apt and easie to be divided, but seems to be the Ferment, by the Benefit of which the Food is dissolved and digested. And therefore it is intimately mixed with it, by the Teeth agitating or stirring them together in mastication.

This Liquor, which we commonly call the Saliva, or Spittle, seems to be a Composition made of two several Juices, very different in their Nature: And therefore the several Parts of it are separated by their proper Glands, and Nature has planted no fewer than four pair about the Mouth, which supply the Juices that make the Saliva; to wit, the *Parotides*, and the *Glandula Nuckiana*, the



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*Glandulæ Maxillares interna*, and *Sublinguales*. Whereas if the *Saliva* were but one more simple Liquor, a less number of Glands might have been sufficient. At least there appears no Reason why one of every Pair should discembogue it self into the Mouth so very near to the Orifice, by which a Gland of some other Pair throws in its Juice; and they are not rather all planted at more equal distances from one another, so to flow in upon every part of the Aliment at the same time.

Not that I suppose, as there are four Pair of salivatory Glands, so there are four sorts of Juices supply'd from them, to make the *Saliva*; but, as I hinted before, that there are only two different Juices that constitute it. And these are not only sufficient, but more proper to excite and secure that Fermentation, which is necessary to Concoction. For we find that most of those Fermentations, which arise upon Mixtures made for Experiments, are produced from the mixture of two things; and it is not so easie to find out three or four such Liquors of a different Nature, as will, upon the mixtion of them all, produce a Fermentation, and from the omission of any one of them discover no Discord or Disposition to ferment: Besides, it is certain that two do better secure the End, which Nature designs. For, if there were three or four different Juices, of which the *Saliva* naturally consists, these must all have their proper Qualities preserv'd to them, or else the Fermentation, which should arise between them, will not necessarily follow upon their mixture; and it is certain, that there would be more

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Danger, that one of three or four should be depriv'd of its natural Quality, than one of two.

What Nature these two Juices are of, I do not pretend positively to determine; but so far as I have been able to make my Conjectures about it from Experiments, I do think one of them to be an acid Juice; the other an oleaginous Liquor, something like Oil of Turpentine. For amongst the many Experiments I have made, there was no one that gave me so much Satisfaction, as that which I made with Oil of Turpentine and Oil of Vitriol, tho' I try'd several other things, that will produce a Fermentation upon their Mixture. And it was for this Reason, that I made the Experiment with Oil of Turpentine and the other Oil.

I took a piece of raw Flesh, and having cut it into pices, but much larger than what our more solid Food is reduc'd to by due Mastication, I mix'd some Crums of Bread with it, then I poured in the Oil of Turpentine to them, and upon that the Oil of Vitriol; and having shak'd them together, I digested them about four hours in *Balneo Mariæ*, and then shaking them again in the Glass, I found the Meat dissolv'd, and they all became a thickish Pulp. I could not but take notice, that Oil of Camphire (tho' it does not otherwise seem much different in its Nature from Oil of Turpentine) and Oil of Vitriol, which upon mixture will produce an effervescence as well as the Oil of Turpentine and Oil of Vitriol, yet did not touch the Meat, upon which I poured them, so as in the least to dissolve them. I



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cannot deny but that an Acid, and a Solution of Salt of Tartar, did diſſolve ſome part of the Fleſh-meat, which I mix'd them with, but yet neither ſo ſoon nor ſo perfectly as the two forementioned Oils. And I do the rather think one of thoſe Juices, which conſtitute the *Saliva*, to be of the Nature of Oil of Turpentine, than of a fix'd Salt, becauſe it will correct and temper even Oil of Vitriol, ſo as to render it more tolerable to the Fibres of the Stomach. Not that I ſuppoſe the acid part of the *Saliva* to come near to the Acidity of Oil of Vitriol. For tho', when they are mix'd, they will make a Liquor that may not be injurious to the Stomach; yet the acid Juice, if it were ſo corroſive as Oil of Vitriol, would certainly be injurious and painful to the ſalivatory Ducts, which convey it to the Mouth before it is mix'd with the oleaginous Liquor. But I only ſay it is an Acid, and in ſome degree approaches to the Nature of that Oil. And Nature, which can much better adapt ſeveral Cauſes for the Production of ſuch an Effect than Art, may attain her End by a more temperate Acid; tho', at the ſame time, we may be able to make ſome probable and true Conjectures about the Nature of thoſe Cauſes from Experiments.

It being moſt reaſonable to ſuppoſe, that there are but two ſorts of Juices, of a different Quality, that make the *Saliva*, I do conceive, that four of the eight ſalivatory Glands, or two pair of the four, do ſupply one of theſe Juices, and the other four Glands the other. And this ſeems to be a very good Reaſon, why they are ſo planted, and the Orifice of their

Ducts

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Ducts ſo order'd, that the Juice, which is ſupply'd by one Gland, is diſcharg'd into the Mouth, very near to the Orifice, by which the Juice of a different Nature is tranſmitted from another, ſo that they muſt neceſſarily meet and mix together. Thus the *Glandulæ Nuckiana*, and *Parotides*, throw in two different Juices by Orifices, which open into the Mouth very near to one another; and the *Glandulæ Maxillares internæ*, and *Sublinguales*, do below ſupply the ſame kind of Juices by Orifices, that open ſo near to one another as to ſecure the mixture of the two different Juices.

Theſe Glands, I ſay, do between them afford two divers ſorts of Liquors, of ſuch a Nature as are apt to ferment upon their firſt Mixture, but perhaps more conſiderably when they come to be digeſted by the Heat of the Stomach. So that the Colluctation, or Fermentation, which attenuates and concocts the Food in the Stomach, does not ordinarily ariſe between the Aliment and the *Saliva*, but between the ſeveral Parts of the *Saliva* it ſelf. And indeed, if the *Saliva* did not conſiſt of two Juices, whoſe Nature is in ſuch a manner different, as to render them apt to ferment upon their mixture, it would be very hard to conceive how it ſhould ſo readily and indifferently ſerve for the Digeſtion of all Eatables; how it ſhould ferment with, and diſſolve ſo great a Variety of things, not only of a different, but of a contrary Nature; how it ſhould ferment with Acids as well as Alkalies, digeſt things thatare cold as well as hot or temperate; ſome things that are ſalt, others that

are inſipid, bitter and ſweet, mucilaginous, oily, &c. But if we ſuppoſe, that the Fermentation, which ſerves for the Digeſtion of the Food, ariſes from a peculiar difference in the Nature of two Juices, which conſtitute the *Saliva*, it will be eaſie to give a rational Account of our Concoction of innumerable things of a different Nature. And this ſeems to be as effectual, and a more certain way to attenuate and diſſolve the groſſer Parts of our Food, than if the Fermentation were made only between the *Saliva* and the Aliment: Beſides, the *Saliva* ſeems to diſcover a Fermentation upon the mixture of its conſtituent Juices, even at thoſe times when we do not actually eat; for it is always attended with Bubbles, and a Froth, when it has not been at all agitated in the Mouth, and many of thoſe Bubbles will remain for ſome conſiderable time after we have ſpit it out.

Nature therefore having appointed the *Saliva* for the digeſtion of the Food, has taken care that it ſhall be thrown in upon the Aliment on every ſide. Thus the *Glandulæ Nuckiana*, and the *Parotides*, ſupply their Juices to that part of the Food, which lies on the outſide of the Gums, between the Cheeks and the Teeth, and the *Glandulæ Maxillares interna*, and *Sublinguales*, do beſtow their Liquor upon the Meat, which is within the Teeth and Gums. Neither has ſhe had a Regard only to that Supply, which is due to all the parts of our Food, but likewiſe to the mixture of the two different Juices of the *Saliva*, which is neceſſary to its Fermentation. And therefore, as I have already obſerv'd, the Orifices

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rifices of the Ducts, which belong to one sort of Glands, are placed near the Aperture of a Duct, which conveys a Juice from one of the other Glands. So the Ducts of the *Glandulæ Nuckianæ*, and the *Ductus Stenoniani*, do on each side open into the Mouth, near one another; and the salivatory Ducts of the *Glandulæ Sublinguales*, and the *Maxillares internæ*, tho' they have distinct Orifices, empty themselves under the same *Papillæ*; and the Juices, which are supply'd by them, meet there, and flow into the Mouth together.

The several Parts of the *Saliva* being discharg'd into the Mouth, in such a manner as to meet and begin a Fermentation, the *Saliva* does, partly as it is agitated with the Food by the Teeth, and some other parts of the Mouth; partly by its own Fluidity insinuate it self into, and mixes with the Food, and not only moistens and softens it, but excites the Fermentation, which is to dissolve it. And when the Aliment is thus mix'd with the *Saliva*, which serves to ferment the whole Mass, it is then to be convey'd into the Stomach, that great digestive Vessel of the Body, where the Fermentation is not only continued but improved.

The Nourishment being convey'd into the Cavity of the Stomach, is there kept for some time in a digestive Heat, all which time it is under a Fermentation produc'd by the different Parts or Juices of the *Saliva*, which are mixed with it; which Fermentation does first agitate the more tenuious or subtil parts of the Food, and puts them into motion, and so with the Fermentation of its own, and those

Alimentary Parts, which it firſt communicates a motion to, improv'd by the Heat of the Stomach, the *Saliva* muſt neceſſarily act upon the groſſer Parts. For the inteſtine motion, which is excited in the Maſs, does not give the Particles, which are fermented, the ſame Tendency, but what is ſo various and confus'd, that they muſt inevitably ſtrike not only one againſt another, but againſt thoſe which are more groſs, ſo as to attenuate them, ſometimes by a Colliſion, which ſtrikes off ſmaller Particles from the larger Parts; ſometimes by a Compreſſion, when the Particles which are in motion, happen to ſtrike directly againſt any groſſer Part, on every ſide of it; ſometimes by a kind of Exploſion. For without doubt the *Saliva*, which is fluid, inſinuates it ſelf into the Interſtices of the more craſs Parts of the Aliment, and whatever is agitated and expanded in thoſe Interſtices, requiring a larger ſpace for the Freedom of its motion, and offering a Violence to every thing that oppoſes its Tendency, will, like Gunpowder included in a Shell, force its way out, and tear to pieces that Matter, which does endeavour to confine it.

Thus the groſſer Parts are broken and divided, until they are at laſt ſo far attenuated as to mix more equally with the Fluid, and with them to make one Pulp or Chylous Maſs. And although I do not apprehend how the Stomach ſhould by its reciprocal motions in Inſpiration and Expiration, be able to break and attenuate any Matter, that will not be ſoften'd and diſſolv'd by Agitation in a Liquid; yet it is certain that

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theſe motions, cauſed by the Diaphragm and Abdominal Muſcles in Reſpiration, do make thoſe Parts, which are broken off, as they are diſſolv'd, mix intimately with the more liquid; as the Meat, which I digeſted with Oil of Turpentine, and Oil of Vitriol, did by agitation mix more equally with the Oils, and became a Pulpament.

As the Juices, which conſtitute the *Saliva*, do ferment upon their mixture, ſo it is probable, that from their Mixture and Fermentation there reſults ſuch a *Tertium quid*, as is apt to ferment with the Bile. And therefore, when the Aliment has been under the Fermentation, excited by the *Saliva*, a ſufficient time, it is then thrown into the *Duodenum*, where it meets with the bilious Juice, which flows into that Inteſtine from the Liver, from which a new Fermentation ſeems to begin; and the Commotion of the Parts of the Aliment being ſtill continued, does carry on the Buſineſs of Digeſtion until the Food is perfectly concocted: Tho' it is probable, that this new Fermentation ſerves not only for the more perfect Digeſtion of the Food, but likewiſe for the Separation of the Chyle from the feculent Parts.

Neither do I by a random Gueſs, and an ungrounded Conjecture, ſuppoſe that from the Mixture and Fermentation of the two Juices, which conſtitute the *Saliva*, there reſults a Matter, which is apt to ferment with the Bile. But to me the Notion ſeem'd to be confirm'd by an Experiment that I made. For conſidering with my ſelf, that the Bile is generally allow'd to have much of a ſapo-

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nary Nature, I made a Solution of Soap in fair Water, and mix'd it with the Oils of Turpentine and Vitriol first put together, and from their Mixture I observ'd a very easie and gentle Fermentation, which continued for a considerable time.



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## *A Discourse concerning some Influence of* Respiration *on the* Motion *of the* Heart, *hitherto unobserved. By* J. Drake, M. D. F. R. S.

THO' divers accurate Treatises of the *Heart*, and its Action, have been written by Learned Men of several Nations, especially by two of our own Country; the Great Dr. *Harvey*, to whose happy Sagacity this Nation owes the Glory of the Invention of the *Circulation* of the *Blood*; and the incomparable Dr. *Lower*, to whom we are beholding for a compleat display of the *Mechanical Structure* of the *Heart*, and a most ingenious Rationale of its Action. Yet there remain several doubts and difficulties about it (in my Opinion) not sufficiently accounted for, towards the resolving some of which, I shall offer what my own Thoughts have suggested to me, and leave it to the Consideration of the Reader.

The Learned Dr. *Lower* (whose accurate Piece on this Argument will insure his Reputation so long as Physical Knowledge shall last in esteem) has so well accounted for the *Systole*, or Contraction of the Heart from the *Mechanical* Structure of it, that he seems almost to have exhausted the Subject; and had he

he been as happy in diſcovering the true cauſe of the *Diaſtole*, he had left little room for the Induſtry and Sagacity of others about this *Viſcus*.

But having judiciouſly and ſolidly explain'd the *Syſtole*, he contents himſelf to aſcribe the *Diaſtole* to a motion of *Reſtitution*, which Account gives me no ſatisfaction: Becauſe the *Syſtole* being the proper, and (as himſelf confeſſes) the only motion of the Heart, a ſtate of *Contraction* ſeems to be the natural ſtate, and conſequently without external violence, it ſhou'd have no *Diaſtole* at all.

This will appear more plain, if we conſider the Circumſtances of it, and its motion, as a Muſcle, with reſpect to other Muſcles. That Contraction is the proper Action, and State of all Muſcles, is evident from Experience of Fact, as well as Reaſon. For, if any Muſcle be freed from the power of its *Antagoniſt*, it is immediately *contracted*, and is not by any Action of the Will, or Spirits, to be reduced to a ſtate of *Dilatation*. Thus, if the *Muſculi Flexores* of any Joint be divided, the *Extenſores* of that Joint being by that means free'd from the contrary Action of their *Antagoniſts*, that Joint is immediately extended without any conſent of the Will, and in that ſtate it remains; and ſo *Vice verſa*, if the *Extenſores* be divided. From whence it is plain, that the Muſcles have no reſtitutive motion, but what they derive from the Action of their *Antagoniſts* by which they are balanc'd. Thus likewiſe the *Sphincters* of the *Gula*, *Anus* and *Veſica*, having no proper *Antagoniſts*, are always in a ſtate of Contraction, and ſuffer nothing

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thing to pass 'em, but what is forced thro' 'em by the contrary Action of some stronger Muscles, which, tho' not properly to be called *Antagonists*, yet on all necessary Occasions perform the Office of such.

That the Heart is a Muscle, furnish'd and instructed for motion like other Muscles, is (in my Opinion at least) demonstrated beyond contradiction by Dr. *Lower* and others. And, as it is a *Solitary* Muscle without any proper *Antagonist*, and not directly under the power of the Will, nor exercising *Voluntary* motion, it approaches neareſt to the *Sphincter* kind, which only has these Conditions in common with it. But in constant and regular Alternations of Contraction and Dilation, it differs exceedingly from all the Muscles of the Body.

This *reciprocal Æstus* of the Heart has given the Learned abundance of trouble; who, finding nothing peculiar in the Structure, which shou'd necessarily occasion it, nor any *Antagonist*, whose re-action should produce it, have been extreamly perplext to find out the cause of it.

But passing over the various Opinions of Authors, to avoid being tedious, I shall take notice here only of the very Learned Dr. *Lower*'s, in whose Account of the *Systole*, however solid and ingenious, I observe something deficient, and whose *Hypothesis* of the *Diastole* I think to be precarious and false.

This excellent Author, having by sound Arguments drawn from the Structure and Mechanism of the Heart, establisht the Certainty of its *Muscular Motion*, rests satisfied, with-

out taking notice of any Assistance, that the Heart receives from any other Part, except from the Brain, by the means of the eighth pair of Nerves.

The Accurate *Borellus*, in his *Oeconomia Animalis*, computes the *Motive* Power of the *Machine* of the Heart to be equal to, or to surmount that of a Weight of 3000 *l.* The *Obstacles* to the motion of the Blood thro' the *Arteries* he esteems equivalent to 180,000 *l.* which is 60 times as much as he rates the Force of the Heart at. Then deducting 45,000 *l.* for the adventitious Help of the *Muscular Elastick Coat* of the *Arteries*, he leaves the Heart with a Force of 3,000 *l.* to overcome a resistance of 135,000 *l.* that is, with 1 to remove 45.

*Part. 2d. Prop. 67. Prop. 73.*

*Prop. 76.*

This stupendous Effect he contents himself to ascribe to the *Energy* of *Percussion*. But, had he proceeded in his Calculation to the Veins, which he allows to contain constantly a quantity of Blood, quadruple to the Contents of the Arteries, and to which this *Energy* of *Percussion* does either not reach at all, or but very languidly, he might probably have seen a necessity for some other Expedient to remove so insuperable a difficulty.

But not to insist rigorously on the exactness of this Calculation (tho' the great Abilities of the Author in this way, and his Ingenuity and Modesty, are a sufficient Warrant for the accuracy of his Computations, and the fidelity of his Accounts) we may allow a much greater Deduction, than would be justifiable, without lessening the difficulty. But this account

count I have taken notice of purely for the sake of the Calculation, which may be of use in the Sequel, the account it self being in other respects more defective than Dr. *Lower's*, to which we will return.

The Doctor, notwithstanding his great Sagacity, appears (to me) to have overlook'd something of very great moment, and importance in the explication of the Action of the Heart. For, tho' it should be granted, that the *Muscular Fibres* of the Heart acted by the Nerves, are the immediate Instruments of its *Constriction* or *Systole*; yet it must not be denied, that the *Intercostal* Muscles and *Diaphragm* are of great service to aid and facilitate this Contraction, by opening a Passage for the Blood thro' the Lungs, which denied wou'd be an invincible Obstacle.

Neither do they promote it that way only? The manner how they farther assist the Heart in its Contraction, will appear manifestly, if we consider the different Posture, Situation, and Capacity of the Blood-Vessels of the Lungs in the several times of *Elevation* and *Depression* of the *Costa*.

The *Pulmonary* Artery rises from the *right* Ventricle of the Heart, and runs in one Trunk, 'till it comes to the *Aspera Arteria*, where it is divided, and sends a Branch along with each Division of the *Aspera Arteria*, according to all the minutest Subdivisions, of which it is likewise subdivided, accompanying all the *Branchi*, in their whole progress through the Lungs.

The *Pulmonary* Vein, which empties it self into the *Left* Ventricle of the Heart, spreads

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it self on the *Aspera Arteria* and *Bronchi*, in the same manner that the Artery does.

The necessary consequence of this Disposition is, that this Artery and Vein being co-extended with, and fasten'd to the *Bronchi*, must needs suffer such alteration of *Superficial* Dimensions, as the *Bronchi* do in the *Elevation* or *Depression* of the *Costæ*.

While the Ribs are in a state of *Depression* (whether before Commerce with the external Air or after); the *Annular Cartilages* of the *Bronchi* shrink one into another, and by that means their *Dimensions* are exceedingly contracted. In conformity to this condition of the *Bronchi*, the *Pulmonary* Artery and Vein must likewise, either by means of their *Muscular* Coats contract themselves to the same *Dimensions*, or lye in *Folds* or *Corrugations*, which is less probable.

On the other hand, when the Ribs are elevated, and the *Diaphragm* bears downward, the Air rushing into the Lungs, shoots out the *Cartilaginous* Rings, and *divaricates* the Branches of the *Trachea*, and by them extends and divaricates the several Divisions of the *Pulmonary* Artery and Veins, and thereby lengthens and enlarges their Cavities.

This enlargement of their Cavities is very considerable, not only upon the score of the addition, which they receive in length thereby, but also upon the account of their *Divarication*. For whereas, when the Ribs are depress, and the Lungs subside, the Blood-Vessels are not only contracted, (as I have already observ'd) but their Branches, which are exceeding numerous, approach one another,

and

and lie in juxta-position, by which their Cavities are very much compress'd and streightned: When the Ribs are elevated, and the Lungs turgid with Air, not only the Fibres, by which their Coats in the opposite state were contracted, are extended; but those innumerable Vessels, which lying before in lines almost parallel upon one another, compress'd one another, making an *acute* Angle at their Junctures, are divaricated and separated from each other, and make an *obtuse*, whereby their Chanels are widen'd.

Thus a passage is open'd to the Blood, from the *Right* Ventricle of the Heart to the *Left*, thro' the Lungs, to which it cou'd not otherwise pass; and the opposition, which the Blood contain'd in that Ventricle, must otherwise necessarily have made to its Constriction, is taken off, and the *Systole* thereby facilitated.

Nor is that all. For the *Diastole* being caus'd (as I shall in the Sequel shew) by the force of the Blood rushing into the Ventricles, this Ampliation and Extension of the *Pulmonary* Artery is a sort of *Check* or *Counterpoise* to it, and prevents an endeavour towards two contrary Actions at once, which must necessarily frustrate both. For the Heart being a *Springy*, *Compressible* Body, whose proper Action, which is Contraction, depends on the influx of certain Fluids into its Fibres, or Substance; and containing besides a Fluid in its *Ventricles*, or great Cavities, in one of which is the Mouth of this Artery, the action of this Vessel must in great measure resemble that of a *Syringe*, whose extremity is immers'd in Wa-



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ter, the Enlargement or Expansion of the Chanels of the Artery answering the drawing of the *Embolum*, as the constrictive motion of the Muscle of the Heart does the pressure of the *Atmosphere* upon the *Surface* of the Water, the one making way for the fluid, and the other forcing it to follow, where the resistance is least. In this sense we may allow a sort of Attraction to the *Pulmonary*-Artery, depending wholly upon the Action of the *Intercostal* Muscles and *Diaphragm*, which we must therefore confess to be very serviceable and instrumental in promoting the *Systole* of the Heart.

But if the Learned Author be deficient in his account of the *Systole*; that is, if he has not observ'd all the Mechanism and Contrivance of Nature for the Contraction of the Heart; much less sufficiently has he accounted for the *Diastole*, or Dilatation of it, which he ascribes to a motion of *Restitution* of the over-strain'd Fibres, which yet he confesses are made for *Constriction* only. 'Tis true, he immediately after joins the *Influx* of the *Blood* as a concurrent cause; but from the slight notice that he takes of it, 'tis plain, that he did not so much as dream of any great share it had in that action. His words are these:

*De Corde, Pag. 75.* ... *Quin & (ut obiter hoc moneam) cum omnis motus contractione perficiatur, & Cordis Fibræ ad constrictionem solum factæ sint, apparet quoque Cordis motum, totum in* Systole *positum esse; cumq; Fibræ ultra tonum suum in omni constrictione ejus tendantur, idcirco ubi nixus iste absolvitur, motu quasi restitutionis Cor iterum relaxatur, & san-*

*guine*

*guine a Venis* influente *rursus distenditur*; *a* nullo *enim cordis motu, nisi* tensionem suam remittente, *& ab* irruente *sanguine* Diastole *ejus libratis adeo viribus succedit.*

I have transcribed the intire Paragraph, because it contains his whole *Hypothesis* of the *Diastole*, and all the notice that he takes of it thro' his whole Work. But how slender soever this may prove, it is the most substantial that I have any where met with, except a late one of Mr. *Cowper*, which is properly an Improvement of this, and shall be considered in the Sequel.

But, if Contraction be the sole Action of these Fibres (as this Great Man confesses it to be) and as indeed it is of all *Muscular* Fibres, I wonder how so judicious a Writer came to slip into such an absurdity, as to call their Distention (vulgarly but improperly called Relaxation) a Motion of *Restitution*. For from the Nature of those Fibres, and their disposition in the Structure of the Heart, the natural State of the Heart appears manifestly to be *Tonical*, and its Dilatation a State of Violence; and consequently, the Constriction is the *true* motion of *Restitution*, and the State to which it will *spontaneously* return, when the Force is taken off, which is the work of the *Intercostal* Muscles and *Diaphragm*.

Thus we are left still to seek for the true cause of the *Diastole*, which seems to me to be the main and most difficult *Phænomenon*, relating to the Heart and the Circulation of the Blood. But in Mr. *Cowper*'s ingenious *Introduction* to his *Anatomy of Humane Bodies*, I

find the Share which Dr. *Lower* hints the Blood to have in that Action, further prosecuted, and improv'd into the main Instrument of the Dilatation of the Heart, wherein I agree intirely with him. But as to the manner, and reasons of its being so very instrumental, I can't be so perfectly of his mind.

*The Heart* (says this accurate Anatomist) *of an Animal bears a great Analogy to the Pendulums of those Artificial Automata, Clocks and Watches, whilst its motion is performed like that of other Muscles, the Blood doing the Office of a* Pondus.

This Explication, being but a Simile without a distinct application to Particulars, is beside so very short, that I can at best but give a conjecture at the meaning, which if I mistake, I shall deserve to be excused, and expect to be better inform'd.

By the *Blood*'s doing the Office of a *Pondus*, I suppose he means, that the Blood contributes in the same manner to the motion of the Heart, as the *Weights* do to that of the *Pendulum* of a *Clock*. If so, the Blood, according to him, must be the Instrument of *Constriction*; and *Dilatation* mast be the *Natural* State, or *Spontaneous* Motion, to which it wou'd, when under no violence, return; the contrary of which, I presume, will appear ere I have done.

But if he means, that the *Blood* in its reflux, by *gravitating* on the *Auricles* and *Ventricles*, dilates and expands 'em, acting therein as a *Counterpoise* to its contractions as a Muscle, I cou'd wish his Design had not bound him up to

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to ſo narrow a compaſs, and that he had given us an explication at large of ſo abſtruſe and ſo important a *Phænomonon*: Becauſe the *Specifick Gravity* of the Blood ſeems to me a cauſe by no means alone adequate to the effect, which it is here ſuppos'd to produce.

For, if the Blood acts only as a *weight* by meer *gravitation*, then that part of it only which deſcends from the Parts above the Heart can be employ'd in that Action. This at the largeſt computation can't amount to Five pound weight, and muſt, according to the computation of *Borellus*, force a Machine, that is able to overcome a reſiſtance of 135,000 *l.* I leave every man to deduct what he ſhall upon examination find reaſonably to be deducted, and yet ſhall reſt ſecure, that it is not to be effected in the leaſt with ſo ſmall a Weight.

But neither does the *Refluent* Blood gravitate in any ſuch proportion, as I have here aſſign'd. For to make a true eſtimate of its *Gravitation*, we muſt conſider the Circumſtances of the Liquor ſuppos'd to gravitate; in which it very much reſembles Water inclos'd in a recurve Tube, of which, if the length of the two Legs be equal, it may be ſuſpended in the Air full of Water, with the Extremities downwards, without loſing a drop, altho' the *Diameter* of thoſe Legs ſhou'd be very unequal. The Caſe of the Arteries and Veins is pretty near a parallel to a Tube, ſo fill'd and inverted. For, if the Arteries and Veins be continued Tubes, (as by the Microſcope they are made to appear) then ſuppoſing their contents to have no other deter-



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mination of motion, than their own weight wou'd give them, the contain'd Fluids must be counterpoises to each other. For the Veins and Arteries being join'd at the smaller Extremeties, and the larger of both terminating in the same parallel Line, it is impossible, according to the Laws of *Hydrostaticks*, that the contents of either shou'd overbalance t'other. How far then must it fall short of forcing the natural Power and Resistance of so strong a Muscle as the Heart, by meer Gravitation,

The Blood indeed has a *Progressive* Motion thro' its Vessels, wherein it differs from Water, in a recurve Tube, in the Experiment above-stated. But, if the natural Gravitation of the Blood contributes nothing to the Dilatation of the Heart, this progressive motion will not be found much more sufficient. For, as this motion is deriv'd intirely from the Heart's Constriction (as all accounts hitherto derive it) cou'd the Blood be suppos'd to re-act upon the Heart, with all the force first impress'd upon it by the Heart, it wou'd be insufficient, unless we will suppose the *Force communicated* to be superiour to the *Power Communicant*, which is absurd.

But when the just and necessary Deductions for the Impediments, which the Blood meets with in its Progress thro' the Vessels shall be made, the remaining Force will be found so inexceeding weak, that to prop the Blood thro' the Veins may be a task alone too great for so small a Power, without charging it with the additional difficulty of forcing the Muscle of the Heart.

*Alphonsus*

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*Alphonsus Borellus*, after a great deal of solemn pains taken to shew his care and exactness, and to possess his Reader of the truth of his Calculations, casts up the force of the Heart, and the *Muscular* Coat of the Arteries, to be together equal to a weight of 3,750 *l.* and allots 'em a Resistance equal to 180,000 *l.* to overcome which is 45 to 1. To make up for a disproportion, by his own confession, incredible to those who have not considered the matter as he had done, he flings into the Scale the additional *Force of Percussion*, which he leaves *indefinite*, and thinks sufficient to *force any quiescent finite Resistance whatsoever.*

But as this Account and *Hypothesis* are part of a Posthumous Work (if a liberty of Conjecture may be allow'd in so uncertain a matter,) I shou'd suspect, that these Papers were left unfinish'd by *Borellus*; or at least, that in many places the last hand was never put to 'em. For neither in this Place, nor any other of this Work, does he account for any more than the *Systole* of the Heart, and the resistance which is made to the progressive motion of the Blood in the Arteries only. This alone he found to exceed the Power of the Heart so prodigiously, that he seems to shuffle it off his Hands with a general and precarious Solution, as a difficulty that he was desirous to be rid of. For, having ascrib'd this *stupendous* (as he himself calls it) effect to the *Energy of Percussion*, he takes no care to satisfie his Reader any farther about it, or to refer him, or give him the expectation of satisfaction any where else; altho' he has an express Treatise on the *Force of Percussion*, which was written



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preparatory to this, and to which he frequently refers in other Places of this Work. But what confirms my suspicion, that this part was intended for a farther Revise by the Author, is, that he has left the Progress of the Blood thro' the Veins, and the *Diastole* of the Heart, absolutely untouch'd, tho' they are difficulties of a much greater magnitude than this, which he has attempted to account so slightly for: For, in these he is excluded the benefit of *Percussion*; and has yet a greater resistance to overcome without it. Omissions of this kind are so unusual with this Author, where-ever he knows himself to go upon sure grounds, that it is to me an Argument, that he doubted the sufficience of his *Percussion*, and reserv'd these important *Phænomena* for farther consideration, without plunging himself into such an Absurdity, as to ascribe to *Percussion* any such *Energy* as to be able (so broken as it returns to the Heart) by its re-action to force that Power, from whence only it was at first deriv'd.

Dr. *Lower*, and Mr. *Cowper*, deliver their Opinions of the Cause of the Dilatation of the Heart so very short, and without any Arguments to support 'em, that by exposing 'em naked, they seem rather to discourse of it transiently, as men obliged by the nature of their Subjects to say something of it, than solicitous to give any full or satisfactory Account; and therefore I shall proceed no farther upon 'em here.

But tho' the *Hypothesis* of *Borellus* may, in this case, be found precarious or insufficient (a misfortune that has befallen him in divers other

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other Particulars) his *Theory* holds ſtill good. At leaſt it ought to be allowed, in juſtice to his great Abilities and Exactneſs, 'till ſome body convicts him of ſome material Error in his Calculations, which has not as yet been done by any body, that I know of.

Suppoſing then the force of the Heart, and of the *Muſculæ* Coat of the Arteries, as likewiſe of the reſiſtance, which they muſt overcome, to be computed with any degree of accuracy, there remains yet ſuch a prodigious diſproportion to be accounted for, as requires ſome more powerful Agent, than any yet aſſign'd, to make up the deficiency.

What aſſiſtance the Heart receives from the action of the *Thorax* towards the facilitating its contraction, without which aſſiſtance there cou'd have been no *Syſtole*, has been already ſhewn. But neither the *Intercoſtal* Muſcles, or *Diaphragm*, which are ſo inſtrumental in that part of its action, can contribute any thing to the *Diaſtole*; becauſe they ſerve only to enlarge the cavity of the *Thorax*, and thereby to open a paſſage to the Blood from the Heart, and promote its Conſtriction.

Whatever therefore the force is, that dilates the Heart, and is the cauſe of the *Diaſtole*, it muſt be equal to that of the Heart, the *Intercoſtal* Muſcles and *Diaphragm*; to all which it acts as an Antagoniſt. I take no notice of the *Serratus Major Anticus*, and other Muſcles; which have an obſcure ſhare in the *Elevation* of the *Coſtæ*, becauſe as much may reaſonably be deducted upon the account of the *Obliquus externus Abdominis*, and other Muſcles; which having their Inſertions on ſome of the lower *Ribs*, are as inſtrumental towards

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towards the *Depression* of 'em, and so balance the Account. But the chief use of these is in violent Respiration: In ordinary Respiration their share is small.

Such a real Power (which may in the least be suspected of any share in this Action) is hard, perhaps impossible to be found in the *Machine* of any *Animal* Body; and yet without some such Antagonist, it is as impossible the Circulation of the Blood shou'd be maintain'd. All the Engines yet discover'd within the Body, conspire towards the *Constriction* of the Heart, which is the *State* of *Quiescence*, to which it naturally tends. Yet we find it alternately in a *State* of *Violence*, that is, of *Dilatation*; and this upon necessity, because upon this *Alternation* depends all Animal Life.

Some sufficient Cause external must therefore be found, to produce this great *Phænomenon*; which Cause must be either in the *Air*, or *Atmosphere*, because we have no constant and immediate Commerce with any other *Mediums*.

Some great Physicians observing this, and that depriv'd by whatsoever means of Communication with the *external* Air, we became instantly extinct, have imagin'd, that in the Act of Inspiration certain purer parts of the Air mixed with the Blood in the Lungs, and was convey'd with it to the Heart, where it nourish'd a sort of *Vital Flame*, which was the cause of this reciprocal *Æstus* of the Heart. Others not quite so gross, rejecting an *Actual Flame*, have fancied that these fine Parts of Air mixing with the Blood in the Ventricles of the Heart, produc'd an *Effervescence* which dilated it. But these Fancies have been long since

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since exploded and condemn'd upon ample Conviction; and 'tis a Point yet undetermin'd, whether any Air does mix with the Blood at all in the Lungs, or not.

But supposing, that some Air may insinuate it self into the *Pulmonary* Vein, it can no other way dilate the Heart than by an Effervescence in the Left Ventricle, which wou'd not dilate the Right. But this Opinion is contradicted by *Autopsie*, and too laboriously confuted by others, to be brought upon the Stage again here.

There remains therefore only the *gross Body* of the *Atmosphere* to be considered, which is undoubtedly the *true Antagonist* to all those Muscles, which serve for ordinary Inspiration, and the Constriction of the Heart. This will appear more evidently, if we consider not only the power, but the necessity of its Action upon *Animal* Bodies, as well as the want of other sufficient Agents.

The Heart is a *Solitary* Muscle of very great strength, and the *Intercostal* Muscles and Diaphragm, which likewise have no *Antagonists*, are a vast additional Force, which must be balanc'd by the contrary Action of some equivalent Power or other. For, tho' the Action of the *Intercostal* Muscles be voluntary, that does not exempt 'em from the condition of all other Muscles serving for *voluntary* motion, which wou'd be in a State of perpetual Contraction, notwithstanding any Influence of the Will, were it not for the libration of *Antagonist* Muscles. This libration between other Muscles, is answer'd by the *Weight* of the incumbent *Atmosphere*, which presses upon the *Thorax* and other parts of the Body. And, as

as in all other voluntary motions the influence of the Will only gives a prevalence to one of it two Powers before equilibrated, ſo here it ſerves to enable thoſe Muſcles to lift up a weight too ponderous for their ſtrength not ſo aſſiſted; and therefore as ſoon as that aſſiſtance is withdrawn, the *Coſtæ* are again depreſs'd by the meer *Gravitation* of the *Atmoſphere*, which wou'd otherwiſe remain elevated thro' the natural Tendency of thoſe Muſcles to contraction.

This is evidently prov'd from the *Torricellian* Experiments, and thoſe made upon Animals in Mr. *Boyle*'s Engine; where, as ſoon as the Air is withdrawn, and the *preſſure* thereby taken off, the Intercoſtal Muſcles and Diaphragm are contracted, and the Ribs elevated in an inſtant, and can't by any power of the Will be made to ſubſide, 'till the Air is again let in to bear 'em forcibly down.

It were ſcarce worth while to take notice here of a Miſtake of the Learned Dr. *Willis*, were it not for the great Authority of the Man, which is almoſt ſufficient to keep Error in countenace. The Doctor having obſerv'd, that the Fibres of the *External* and *Internal Intercoſtal* Muſcles ran in a contrary order, as it were, decuſſating each other, takes occaſion from thence to fanſie, that there was an oppoſition in their Office; and that as the *External* ſerv'd to raiſe up the Ribs, the *Internal* drew 'em down again, forgetting at that time, That, when a contractile Body is faſten'd at the ſeveral ends to Points unequally moveable, let the Contraction happen in what part or manner ſoever

*De Reſpirationis Organis & Uſu.*

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ver, the more moveable Point muſt be drawn towards the leſs moveable: By which Rule, whether *External* or *Internal Intercoſtals* be contracted, the lower Ribs will be forc'd to approach the upper, that is, be rais'd up.

As in the Elevation of the *Coſtæ*, the Blood, by the paſſage that is open'd for it, is in a manner ſolicited into the Lungs,; ſo in the Depreſſion of 'em, by the ſubſidence of the Lungs, and the contraction of the Blood-Veſſels, both which are conſequent thereof, the Blood is forcibly driven, as it were with an *Embolum*, thro' the Pulmonary Vein into the Left Ventricle of the Heart. And this, together with the *general Compreſſion* of the *Body* by the *weight* of the *Atmoſphere*, which ſurrounds and preſſes upon the whole Surface of it, is that Power which cauſes the Blood to mount in the Veins, after the force impreſs'd upon it by the Heart is broken and ſpent, and which is ſufficient to force the Heart from its natural State to Dilatation.

He that is able to compute the weight of a Column of Air, equal to the Surface of the whole Body, will readily grant it a power ſufficient for the Effects, which are here aſcrib'd to it. And when he conſiders, that the Bodies of Animals are compreſſible Machines, he will find that it muſt of neceſſity affect them in the manner here laid down. But tho' our Bodies be entirely compos'd of *Tubuli*, or Veſſels fill'd with Fluids; yet this preſſure, how great ſoever, being equal, cou'd have no effect upon 'em, if the ſuperficial Dimenſions were not eaſily variable; becauſe being compreſs'd on all parts with the ſame degree of Force, the contain'd Fluids cou'd not any where

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where begin to recede, and make way for the rest to follow, but wou'd remain as fix'd and immoveable as if they were actually solid. But by the Dilatation of the *Thorax*, room is made for the Fluids to move, and by the Coarctation of it fresh motion is impress't, which is the main Spring whereby the Circulation is set and kept going.

This reciprocal Dilatation and Contraction of the superficial Dimensions of the Body, seems so necessary to Animal Life, that there is not any Animal so imperfect as to want it, at least none to the inward Structure, of which our Anatomical Discoveries have yet reach'd. For, tho' most kinds of *Fish* and *Insects*, wants both *moveable* Ribs and Lungs, and consequently have no dilatable *Thorax*, yet that want is made up to 'em by an *Analogous* Mechanism, answering sufficiently the Necessities of their Life.

Those Fishes which have no Lungs, have *Gills*, which do the *Office* of Lungs, receiving and expelling alternately the Water, whereby the *Blood-Vessels* suffer the same alteration of Dimensions, that they do in the Lungs of more perfect Animals.

The Lungs or *Air-Vessels* of Insects, are yet exceedingly more different in Structure, Distribution, and Situation from those of perfect Animals, than those of Fishes are, and yet in their Use and Action agree perfectly with both; that is, *receiving* and *expelling* the Air, and *varying* the *Dimensions* and *Capacities* of the *Blood-Vessels*. These having no *Thorax*, or separate Cavity for the Heart and Air-Vessels, have the latter distributed thro' the whole Trunk of their Bodies, by which they communicate

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communicate with the *External* Air through several *Spiracula* or *Vent-holes*, to which are fasten'd so many little *Trachea*, or Wind-pipes, which thence send their Branches to all the Muscles and *Viscera*, and seem to accompany the Blood-Vessels all over the Body, as they do in the Lungs only of perfect Animals. By this disposition in every *Inspiration*, the whole Body of these little Animals is inflated, and in every *Expiration* compress'd; and consequently the Blood-Vessels must suffer a *Vicissitude* of Extension and Contraction, and a greater motion must thereby be impress'd upon the Fluids contain'd in 'em, than the Heart, which does not in those Creatures appear to be Muscular, seems capable of giving.

The only Animal that is exempted from this necessary condition of *Breathing*, or *receiving* and *expelling alternately some Fluid* into and out of the Body, is a *Fœtus*. But this, while included in the Womb, has little more than a *vegetative* Life, and ought scarce to be reckon'd among the number of *Animals*. For, were it not for that small share of *Muscular* Motion, which it exercises in the Womb, it might without absurdity be accounted for as a Graft upon, or Branch of the Mother.

Concerning the immediate matter, and means of Life, and Nutrition, Authors are not agreed, nor is it the business of this place to reconcile, or decide their differences, but to account for the motion of the Blood thro' the Vessels only. In order to this, it will be necessary to observe, that the Pulsation of the Heart in a *Fœtus* is so very weak and obscure, and the motion of the Blood so extream slow

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and languid, as to be scarce, if at all, perceivable, as has been experienced in the Dissection of Puppies before Respiration had.

*Boyle of the Elasticity of Air. Pechlinus de Aeris & alimenti defectu.*

To produce such a feeble Palpitation, and creeping Motion, no greater force seems to be required, than may be deriv'd from the Communication between the Vessels of the Mother and *Fœtus* in the *Placenta*. I am not ignorant, that divers very Learned Anatomists (whom the Crowd have implicitly follow'd) have absolutely rejected all Communication between these Vessels. But, with submission to Great Authorities, I think they have acted arbitrarily, and without sufficient Warrant from Reason or Experiment: For neither are the Arguments which they bring against it conclusive, nor the Office which they assign to the Umbilical Vessels in lieu of it, proper, or natural to those Vessels, or the reality of the Fact made out by any substantial Reasons. Those that reject this Communication usually do it in favour of one or both of these Opinions, that the Arteries of the *Uterus* do depositе a Nutritive Juice, or a Juice impregnate *with Air* in the *Placenta*, which is suck'd in by the *Umbilical* Vein, and convey'd to the *Fœtus*, for the necessary Uses of Nutrition and Life. Now those that patronize either of these Opinions, lead Nature an unnecessary Dance. For if the *Maternal* Blood does really contain any such *Nutritious*, or any such necessary *Aerial Particles*, why shou'd they be separated and extravasated, to be with difficulty receiv'd into the *Umbilical* Vein, and again

gain mixt with the Blood, when they might more easily have been imparted by the plain simple way of Transfusion from the Arteries of the *Mother* to the Veins of the *Fœtus*. And, that this is the course which Nature takes in this case, I am perswaded from the easiness and simplicity of the Method, which readily performs what might be perhaps in vain expected from t'other, and wou'd over and above find 'em, what they seem to grope so blindly about for, a first Mover of the Blood in a *Fœtus*.

Those that contend for the conveyance of the *Nutricious* Juice, thro' the *Umbilical* Vein from the *Placenta*, are forced upon two difficulties next to Absurdities. For first, they are oblig'd to make this Vein, which, as all other Veins, seems dedicated to the re-conveyance of Blood only, the proper and immediate Chanel, thro' which a very different Liquor is to be carried; and next, to give a Power of Attraction or Suction to it; because the *Nutricious* Juice, which it is thus destin'd to carry, is both viscous and stagnant, and has neither force to drive, nor subtilty to penetrate, or insinuate it self into the Capillary Veins; and therefore must be drawn or suckt as *Milk* is from the *Breast*, to which the *Placenta* and its *Nutricious* Juice are by the Favourers of 'em expresly compared. But if this were the sole use of the *Placenta*, and *Umbilical Vessels*, why were the Umbilical *Arteries* sent along with the Vein? Their business is not to bring any thing back to the *Fœtus*, nor can they contribute any thing to the benefit of the *Mother*; for the *Uterine* Arteries bring



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all to the *Placenta*, the Umbilical Vein carries it to the *Fœtus*, and the *Uterine* Veins convey back again the Surcharge of the *Mother's* Blood; the Umbilical *Arteries* only, have nothing to do, and are superfluous and impertinent, which is contrary to the constant practice of Nature. Yet if *Autopsie* did in the least countenance this Hypothesis, some defence might still be made; but we find in the Umbilical *Vein* of a *Fœtus* nothing but *Florid* Blood, such as in all probability it received immediately from the *Arteries* of the *Mother* without any mixture. And therefore I can't help concluding, that this Opinion engages its Favourers in some Absurdity, without Necessity and without Proof.

They that from the *Placenta* supply the Body of the *Fœtus* with *Air*, are as much distress'd as t'other; for they are forc'd to beg the Question twice, which, even when granted, will not answer their ends. First, they suppose, that an intimate mixture or confusion of *Air* with the *Blood*, is necessary for the support of Animal Life, a *Postulatum*, which perhaps the former part of this Discourse may have render'd unnecessary; and next that, the *Fœtus* is supply'd with *Air* from, and its *Blood* mixt with it in the *Placenta*.

But here again they fetch a Compass without necessity or proof. For if a mixture of *Air* were necessary to a *Fœtus*, why should it be separated from the *Mother's* Blood, and not rather both communicated together, since it is so much more easie and commodious. But neither does the *Placenta* seem to be instructed

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structed and provided for the separation of *Air*, but of a much *grosser Fluid*, destin'd to some other use, which *Autopsie* confirms: Yet, were both those Opinions true, they are however defective, and the Circular Motion of the Blood unprovided for.

By the way of *Transfusion*, this great Phænomenon is naturally accounted for, and the ends, for which the other two Hypotheses were divis'd, might both be answered with more ease. For the *Hysterick* Arteries transmitting their Blood immediately to the *Umbilical* Vein, may very easily transmit such *Nutricious* Juices or *Aerial* Particles, as are contain'd in the Blood along with it, without depositing 'em by the way. By this means so much of the Impulse of the Mother's Blood is preserv'd, as suffices to maintain that languid Circulation which a *Fœtus* enjoys. For the Blood being driven thro' the *Arteries* of the *Uterus* into the *Umbilical Vein*, is convey'd directly to the *Sinus* of the *Porta*, and thence by a short and direct passage thro' the *Cava* to the Heart; where passing thro' the *Foramen Ovale* to the *Left* Ventricle, and thro' the *Canalis Arteriosus* from the *Right* and *Pulmonary* Artery, it is all deliver'd without coming at the *Lungs* to the *Aorta*, and from thence again by the *Umbilical Arteries* to the *Veins* of the *Uterus*, making a sort of *Epicycle* to the main Circulation in the Mother.

As this Opinion is favour'd by the structure and disposition of the Blood-Vessels on both parts, so there is nothing in it difficult to be conceiv'd, or repugnant to experience. Late Discoveries have made it appear, that the Ar-



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teries and Veins are continued Tubes, and that the latter contain nothing but what they receive from the former, and no reaſon appears why we ſhou'd think this Method to be varied in the *Placenta*. On the other hand, if the Arteries of the *Uterus* were continued to the Veins of the *ſame* part, and thoſe of the *Fœtus* in like manner, without communicating with each other, their confluence in the *Placenta* ſeems to be altogether impertinent, and of no uſe, and the *Umbilical* Arteries and Vein fram'd for no other ſervice or purpoſe, than to give the Blood room for an idle Sally.

Thus the reaſonableneſs of this old Opinion may be vindicated, but the certainty of it reſts upon ſtronger proof. Mr. *Cowper*, to whoſe happy Induſtry we owe the Confirmation of many ancient Diſcoveries, and the benefit of ſome new ones, has the honour to re-eſtabliſh this old, but long exploded Truth. For by pouring *Mercury* into a Branch of the *Uterine Artery* of a *Cow*, that went into one of the *Cotyledones* of the *Uterus*, he fill'd thoſe Branches of the *Umbilical* Veins, which went from that *Cotyledon* to the *Navel* of the *Fœtus*; which, with a part of the *Uterus*, he keeps prepared by him.

It wou'd be a weak Objection, to alledge, that the Obſervation and Experiment being made on the *Uterus* of a *Cow*, the Inference wou'd not hold from thence to a *Woman*, the one being *Glanduliferous*, and the other *Placentiferous*; ſince ev'ry one of theſe *Cotyledones*, or *Uterine Glandules*, is in all reſpects a little *Placenta*, and all the difference between 'em is in number, name, and magnitude. Why *Ruminants*

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*minants* differ in this Particular from other *Viviparous* Animals, is beſide the Subject of our preſent Enquiry. But the great Flux of Blood, which conſtantly follows upon drawing the *Placenta* from Women (which is frequently ſo great as to coſt 'em their Lives) is as plain a demonſtration to Reaſon of the *Continuity* of the Veſſels, as Mr. *Cowper*'s Experiment is to the Eye.

I have heard it objected by very learned Men, that if there were ſuch a *Continuity* of Veſſels, and ſuch *Transfuſion* of Blood, the *Fœtus* muſt neceſſarily periſh thro' loſs of Blood, upon the ſeparation of the *Placenta* from the *Uterus*; but that, on the contrary, no viſible flux of Blood does follow while the *Fœtus* continues wrapt in the Membrane, in which condition it may be kept alive ſome hours. To this it may be anſwer'd, that the Circulation in the *Fœtus*, being deriv'd from the Mother, may be ſuppos'd wholly to ceaſe upon the cutting off the Communication between 'em, 'till it is again renew'd more forcibly by *Reſpiration*. But if we allow the motion already impreſs'd upon the Blood to be ſufficient to keep it going a little while; yet it muſt needs be ſo exceeding languid, that the meer reſiſtance of the external Air muſt be more than enough to hinder any Efflux of Blood from a *Fœtus* before Reſpiration. How long Life may be preſerv'd without an *actual* Circulation of the Blood, is a queſtion not of this place. But we have been convinc'd by many and notorious Obſervations and Experiments, that Life has been recover'd a long time after all tokens of Reſpiration, Circula-



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tion, or even Life it self have disappear'd, so that we can't think the first Solution either impossible or improbable.

I expect to be told, that in the early days of *Gestation* in *Viviparous* Animals there is no *Placenta*, or any Adhesion of the *Umbilical* Vessels to any part of the *Mother*, and consequently no such *Transfusion*; and that in *Oviparous* there is no *continuity*, or *communication* of Vessels of any kind, during the whole time of *Incubation*.

But these Objections carry neither the weight nor difficulty along with 'em, that they may be suppos'd to do; for in those days there is neither *Blood* nor *Blood-Vessels*, and consequently there can be no *Circulation* of the Blood; and the *Embryo*, of what Species soever, is no more than a *Vegetable* at that time; nor does the *Fœtus* of any *Viviparous* Creature enjoy any *Circulation*, or shew any signs of Animal Life, 'till after those Vessels, as well as others requisite to the Circulation, are compleated.

It must be confess'd, that *Oviparous* Animals are denied the Benefit of this Communication; but that want is sufficiently compensated by a peculiar Mechanism, which directly answers the ends of *Respiration*, and the *pressure* of the *Atmosphere* upon the *Fœtus*. There is at the *obtuse* end of an Egg a small Cavity fill'd with Air, which is the succedaneous Instrument to the *Respiratory* Organs. For as soon as the Contents begin to be warm'd by the *Incubation* of the Hen, or *any analogous* Heat of *Furnace* or *Dunghil*, the several Humors of the Egg require a *fermentative* motion,

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tion, and the *Air* contain'd in the *Cavity* or *Vesicle*, at the *obtuse* end of the Egg is rarefied, and the Vesicle extended and enlarg'd, and consequently the other Contents are compress; to which the *fermentative* motion naturally resists. But both Bodies being as well *compressible* as *dilatable*, and both having an *expansive* motion impress upon 'em by *Incubation*, the compression and renitency will be mutual, but varied in degree, according as either, thro' the variation of Circumstances, shall prevail. By this means, an Alternation of Compression and Dilatation will be produc'd in both, answering the *respiratory* motion by which a motion will be communicated, which, as soon as the Organs by which it shou'd be regulated are compleated, will in the Body of the *Pullus* be *regular* and *circulatory*.

*Fabritius* ab *Aquapendente*, and after him, our Great Dr. *Harvey*, have assign'd divers Uses to this Cavity or Air Vesicle, the Extravagance of which have perhaps deterr'd others from enquiring so much into the Use, as the Importance of it requir'd. But tho' I can't agree to that *Perspiration*, *Refrigeration*, and *Respiration*, which they make it the Instrument of; yet perhaps the *Air*, that was inclos'd in that *Cavity*, may thro' the augmentation of the Body of the *Pullus*, and its own *Rarefaction* (which is at last so great as to occupy half the Shell) break the *Membrane*, which separted it from the *Pullus*, and thereby give so much *Respiration* as to form the *chirping Voice*, which is often heard before the breaking of the Shell, and with it give

an Addition of Strength to enable it to break the Shell. But how it ſhou'd reſpire ſooner, is to me inconceivable.

There are many Problems of great ſeeming difficulty, the Solutions of which flow naturally from what has been laid down here: But intending to proſecute this Subject farther, and to treat of the Impediments of Reſpiration, and the Conſequences of Reſpiration obſtructed or intermitted, I ſhall reſerve 'em for that opportunity, and content my ſelf here to attempt the *Harveyan* Problem only, which has given abundance of Authors ſo much perplexity.

That incomparable Philoſopher enquires, *Why a* Fœtus, *taken out of the* Uterus *with the* Membranes *intire, ſhall live in Water ſome hours without communication with the* external Air; *whereas if it be taken out and ſuffer'd once to breath, it can't afterwards ſurvive a moment without the benefit of* Reſpiration.

Granting the Fact to be as he has deliver'd it, which yet is not ſo in all caſes, the main difficulty is grounded on a miſtake, which from the ſtating of the Queſtion I find this Great Man to have ſlipt into. For he thinks, that a *Fœtus* is ſooner ſuffocated after having once breath'd, than if it had not breath'd at all, and that by breathing it had contracted ſomething which render'd it more periſhable. *Idem tamen ſecundis exutus*, (ſays he) *ſi ſemel* aerem *intra* Pulmones *attraxerit, poſtea ne momentum quidem temporis abſq; eo durare poſſit, ſed confeſtim moriatur.* And preſently after, *Siquidem conſtat, fœtum, poſtquam* eum ſemel *hauſerit, citius ſuffocari, quam cum*

ab

*ab* illo prorsus *accebatur.* The Doctor observing a *Fœtus* to live longer without Respiration, and to dispence better with the want of Air while included in the Membranes intire, than it cou'd afterwards; infers thence, that the Air does in the first Act of Inspiration impress upon the Lungs some quality, which renders it ever after more indispensably necessary. But allowing his Observation, I must yet deny his Inference to be good: For deprive a *Fœtus* of means of respiring, and then take it out of the Membranes, and it shall be as soon suffocated, as if it had respired before. This proves, that this necessity of intercourse with the Air, by way of the Lungs, is not the Offspring, but the Parent of Respiration, and that, that Learned Man was drawn into a Fallacy of *Non causa pro causa.*

The reason of this Necessity is the pressure of the external Air upon the Surface of the Body, from which it was defended by the interposition of the Membranes and the Humors contain'd, which are not so compressible as the Body of the *Fœtus* it self. So soon therefore as the *Fœtus* is excluded, and expos'd to the immediate contact of the ambient Atmosphere, the Vessels and all the Cavities of the Body must necessarily be so compres's'd, that the Fluids can't have room for motion, and consequently the *Fœtus* cou'd have no Life, if Nature had not contriv'd by the motion of the *Thorax* to remove and admit that pressure alternately, and thereby to impress a motion on the Fluids, which is the Spring of Life. But this motion of the *Thorax* being any way suppres's'd, the equal pressure of the Atmosphere

sphere on all parts occasions a total Cessation of Motion, which is Death.

I shall prosecute this Subject no farther now, nor trouble the Reader with any Apology, for dissenting from those Great Men herein named; because, I hope, I have done it with modesty, and all the respect due to so great Authorities, and have assign'd nothing which is not matter of Fact uncontroverted, or deduc'd from it by plain mechanical Necessity.

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*Some*

## *Some Thoughts and Experiments concerning* Vegetation. *By* John Woodward, *M. D. of the College of Physicians, and R. S. and Professor of Physick in* Gresham College.

THE *Ancients* generally intituled the *Earth* to the Production of the *Animals*, *Vegetables*, and *other Bodies* upon and about it; and that for that reason 'twas, that they gave it so frequently the Epithets of *Parent* and *Mother* *. They were of opinion, that it furnished forth the *Matter* whereof *those Bodies* consist; and received it all back again at their Dissolution for the Composure of *others*. Even those who asserted *four Elements*, supposed that the *Earth* was the *Matter* that *constituted* those Bodies; and that *Water* and the *rest*, serv'd only for the *Conveyance* and *Distribution* of that *Matter*, in order to the *forming* and *composition* of them. 'Tis true, *Thales*, a Philosopher of the first rank in those early Ages, has been thought to have Sentiments very different from these; but that without just Grounds, as I think I have sufficiently proved in another Paper, which I am ready to produce.

* *Terra Parens.* Γῆ μήτηρ πάντων. *Terra Mater.*

But

But tho' *Antiquity* thus gave its *Vote* for *Terrestrial Matter*, several of the *Moderns*, and some of very *great Name* too, both *here* and *abroad*, have gone quite counter, and given *theirs* in behalf of *Water*. The *Dignity* of the *Persons* that have espoused it, as well as their *Numbers*, renders this Doctrine very considerable, and well worth our enquiring into. The great Restorer of *Philosophy* in this last Age, my Lord *Bacon*, is of opinion, *That for Nourishment of* Vegetables, *the Water is almost all in all*; *and that the Earth doth but keep the Plant upright, and save it from over-heat, and over-cold* †. Others there are who are still more express; and assert Water to be the only Principle or Ingredient of all natural things. They suppose that, by I cannot tell what Process of Nature, Water is *transmuted* into *Stones*, into *Plants*, and, in brief, all other Substances whatever. *Helmont*, * particularly, and his *Followers*, are very positive in this; and offer some *Experiments* to render it credible. Nay, a very *extraordinary Person* of our own *Nation* † tries those *Experiments* over again; and discovers a great Propensity to the same Thoughts and Opinion they had; declaring for this *Transmutation of Water* into *Plants* and *other Bodies*, tho' with great Modesty and Deference, which was his usual manner.

† *Nat. Hist. Cent.* 5. §. 411.

* *Complexionum atque Mistion. Element. Figm.*

† Mr. *Boyl*, *Scept. Chym. par.* 2.

The *Experiments* they insist upon are chiefly *two*; the *first* is, that *Mint*, and several *other Plants*

*Plants* prosper and thrive very greatly in *Water*. The *other* is this; they take a certain quantity of *Earth*, and *bake* it in an *Oven*; then they weigh it, and put it into an *Earthen Pot*. Having well water'd this *Earth*, they make choice of some fit *Plant*, which, being first carefully *weigh*'d, they *set* in it. There they let it grow, continuing to *water* it for some time, 'till 'tis much advanced in *bigness*: Then they take it up; and tho' the *Bulk* and *Weight* of the *Plant* be much greater than when *first set*, yet upon *baking* the *Earth*, and *weighing* it, as at first, they find it little or not at all diminished in *weight*; and therefore conclude, 'tis not the *Earth* but *Water*, that nourishes and is *turn'd* into the Substance of the *Plant*.

I must confess I cannot see how *this Experiment* can ever be made with the *nicety* and *justness* that is requisite, in order to *build* upon it so *much* as *these Gentlemen* do. 'Tis hard to weigh *Earth* in that *quantity*, or *Plants* of the *size* of those they mention, with any great *exactness*; or to *bake* the Earth with that *accuracy*, as to reduce it *twice* to just the *same Dryness*. But I may wave all this; for tho' the *Experiment* be never so easily practicable, and all the Accidents of it exactly as they set forth, yet nothing like what they *infer* can possibly be concluded from it; unless *Water*, which they so plentifully bestow upon the *Plant* in *this Experiment*, be *pure*, *homogeneous*, and not charged with any *terrestrial Mixture*; for if it be, the Plant after all may owe its *growth* and *increase* intirely to *that*.

Some

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Some *Waters* are indeed so very *clear* and *transparent*, that one would not easily suspect any *terrestrial Matter* were latent in them; but they may be *highly saturated* with such *Matter*, tho' the Eye be not presently able to descry or discern it. 'Tis true, *Earth* is an *Opake Body*; but it may be so far dissolved, reduced to so extreme small Particles, and these so *diffused* through the *watery Mass*, as not sensibly to impede *Vision*, or render the Water much the less *diaphanous*. *Silver* is an *Opake*, and indeed a very *dense Body*; and yet, if perfectly *dissolved* in *Sp.* of *Nitre*, or *Aqua Fortis*, that is *rectified* and thorowly *fine*, it does not *darken* the *Menstruum*, or render it less *pellucid* than before *. And other Instances there are, that oftentimes *great quantities* of *Opake Matter* are sustain'd in *Fluids*, without considerably striking the *Eye*, or being perceived by it. So that were there *Water* any where found so *pure*, that the quickest Eye could discover in it no *terestrial Intermixture*; that would be far short of a *Proof*, that in reality there was *none*.

* *Provided the* Silver *be* pure *and absolutely* refin'd: *For the least admixture of* Copper *will produce a* blue Tincture *in the* Menstruum; *as* that *of some* other Bodies, *one* different.

But after all, even the *cleareſt Water* is very far from being *pure* and wholly *defecate*, in any part of the World that I can learn. For Ours here, I have had an Opportunity of examining it over a good part of *England*; and cannot say I ever met with any, that, however fresh and newly taken out of the Spring, did

not

not exhibit, even to the naked Eye, great numbers of exceeding small terrestrial Particles disseminated through all parts of it. Thicker and grosser Water exhibits them in still greater Plenty.

These are of two general kinds. The one a vegetable terrestrial Matter, consisting of very different Corpuscles; some whereof are proper for the formation and increment of one sort of Plant, and some of another; as also some for the nourishment of one part of the same Plant, and some of another. The other kind of Particles sustain'd in Water are of a Mineral Nature. These likewise are of different sorts. In some Springs we find Common Salt, in others *Vitriol*, in others *Alum*, *Nitre*, *Spart*, *Ochre*, &c. nay, frequently several of these, or other Minerals, all in the same Spring; the Water as it drains and passes thorough the *Strata* of Stone, Earth, and the like, taking up and bearing along such loose Mineral Corpuscles, as it meets with in the Pores and Interstices of those *Strata*, and bringing them on with it quite to the Spring. All Water whatever is much charged with the Vegetable Matter, this being fine, light, and easily moveable. For the Mineral, the Water of Springs contains more of it than that of Rivers, especially when at distance from their Sources; and that of Rivers more than the Water that falls in Rain. This I have learn'd from several Trials, which I must not give Account of here; my Drift in this place being only to evince the Existence of terrestrial Matter in Water.

Any

Any one who deſires farther ſatisfaction in this, may eaſily obtain it, if he only put Water into a clear Glaſs Viol, ſtopping it cloſe, to keep Duſt and other exterior Matter out, and letting it ſtand, without ſtirring it for ſome Days: He'll then find a conſiderable Quantity of terreſtrial Matter in the Water, however pure and free it might appear when firſt put into the Viol. He'll in a very ſhort time obſerve, as I have frequently done, the Corpuſcles that were at firſt, while the Water was agitated and kept in motion, ſeparate, and hardly viſible *, by degrees, as the Water permits, by its becoming more ſtill and at reſt, aſſembling and combining together; by that means forming ſomewhat larger and more conſpicuous *Molecula*. Afterwards he may behold theſe joining and fixing each to other, by that means forming large thin Maſſes, appearing like *Nubecula*, or Clouds in the Water; which grow more thick and opake, by the continual appulſe and accretion of freſh Matter. If the ſaid Matter be chiefly of the Vegetable kind, 'twill be ſuſtain'd in the Water; and diſcover at length a green Colour, becoming ſtill more and more of that Colour, I mean an higher and more ſaturate Green, as the Matter thickens and encreaſes. That this *Matter* inclines ſo much to that *Colour*, is the leſs ſtrange, ſince we ſee ſo large a ſhare of it, when conſtituting Vegetables wearing the ſame Colour in them. But if there be any conſiderable quantity of meer Mineral Matter in the Water, this, being

* *To ſay nothing of thoſe that were not diſcernible.*

of

of a greater specifick Gravity than the Vegetable, as the Particles of it unite and combine in such Number, 'till they form a *Molecula*, the Impetus of whose Gravity surpasses that of the Resistance of the Water, subsides a great deal of it to the *bottom*. Nor does it only fall down it self, but frequently entangling with the *Vegetable Nubecula*, forces them down along with it.

The Reason why Bodies, when dissolved and reduced to extreme small Parts, are sustain'd in Liquors that are of less specifick Gravity than those Bodies are, hath been pointed at by a late ingenious Member of this Society *. He is indeed far from having adjusted all the *Momenta* of this Affair; however it must be admitted, that, in the *dividing* or *solution* of Bodies, their Surfaces do not decrease in the same Proportion that their Bulk does. Now the Gravity of a Body, which is the Cause of its sinking or tendency downwards, is commensurate to its Bulk; but the Resistance that the Liquor makes, is proportion'd, not to the Bulk, but to the extent of the Surface of the Body immersed in it. Whence 'tis plain, a Body may be so far divided, that its Parts may be sustain'd in a Fluid, whose specifick Gravity is less than that of the said Body. Nay, 'tis Matter of Fact that they frequently are so; and we daily see *Menstrua* supporting the Parts of *Metals*, and other Bodies, that are of six, ten, nay, almost twenty times the Spec. Grav. of those *Menstrua*. And as the Parts of Bodies when divided, are thus supported in a Fluid;

* Mr. *W. Molineux*, *Philos. Transf. No.* 181.



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so when they occur and unite again, they must sink of course, and fall to the Bottom.

Upon the whole, 'tis palpable and beyond reasonable Contest, that *Water* contains in it a very considerable Quantity of terrestrial Matter. Now the Question is, to which of these, the Water, or the Earthy Matter sustain'd in it, Vegetables owe their Growth and Augment: For deciding of which, I conceive the following Experiments may afford some Light; and I can safely say, they were made with due Care and Exactness.

## *Anno* 1691.

I chose several *Glass Viols*, that were all, as near as possible, of the same shape and bigness. After I had put what Water I thought fit into every one of them, and taken an Account of the weight of it, I strain'd and ty'd over the Orifice of each Viol, a Piece of Parchment, having an hole in the middle of it, large enough to admit the Stem of the Plant I design'd to set in the Viol, without confining or straightning it so as to impede its *Growth*. My Intention in this, was to prevent the inclosed Water from evaporating, or ascending any other way than only thorough the Plant to be set therein. Then I made choice of several Sprigs of Mint, and other Plants, that were, as near as I could possibly judge, alike fresh, sound, and lively. Having taken the weight of each, I placed it in a Viol, order'd as above; and as the Plant imbib'd and drew off the Water, I took care to add more of the same

same from time to time, keeping an Account of the weight of all I added. Each of the Glasses were, for better distinction, and the more easie keeping a Register of all Circumstances, noted with a different Mark, or *Letter*, *A*, *B*, *C*, *&c.* and all set in a Row in the same Window, in such manner that all might partake alike of *Air*, *Light*, and *Sun*. Thus they continued from *July* the Twentieth, to *October* the Fifth, which was just Seventy seven Days. Then I took them out, weigh'd the Water in each Viol, and the Plant likewise, adding to its weight that of all the Leaves that had fallen off during the time it stood thus. And Lastly, I computed how much each Plant had gain'd; and how much Water was spent upon it. The Particulars are as follows.

'(A.) *Common Spear-Mint*, set in *Spring-Water*. The Plant weighed when put in *July* 20. just 27 Grains; when taken forth, *Octob.* 5. 42 Grains: So that in this space of 77 Days, it had gained in weight 15 Grains.

'The whole Quantity of Water expended, during these 77 Days, amounted to 2558 Gr. Consequently the weight of the Water taken up, was $170\frac{8}{15}$ times as much as the Plant had got in weight.

'(B.) *Common Spear-Mint*, *Rain-Water*. The Mint weigh'd, when put in, Gr. $28\frac{1}{4}$; when taken out Gr. $45\frac{3}{4}$, having gain'd in 77 Days Gr. $17\frac{1}{2}$.



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'The Dispendium of the Water Gr. 3004, 'which was $171\frac{2}{3}$ times as much as the Plant 'had received in weight.

'(C.) *Common Spear-mint, Thames-water.* The 'Plant when put in, Gr. 28, when taken forth, 'Gr. 54. So that in 77 Days it had gained 'Gr. 26.

'The Water expended, amounted to Gr. '2493. which was $95\frac{11}{13}$ times as much as the 'additional weight of the Mint.

'(D.) *Common Solanum*, or *Night-shade: 'Spring-water.* The Plant weigh'd, when put 'in, Gr. 49; when taken out 106, having 'gain'd in 77 Days 57 Gr.

'The Wat. expended during the said time, 'was 3768 Gr. which was $65\frac{1}{57}$ times as much 'as the Augment of the Plant.

'*This Specimen* had several *Buds* upon it, 'when first set in the Water. *These* in some 'Days became fair *Flowers*, which were at 'length succeeded by *Berries.*

'(E.) *Lathyris seu Cataputia Gerh. Spring-'Water.* It weigh'd, when put in, Gr. 98. 'when taken forth, Gr. $101\frac{1}{2}$. The additional 'weight for this whole 77 Days, being but 'Gr. $3\frac{1}{2}$.

'The Quantity of Water spent upon it, du-'ring that time, Gr. 2501. which is $714\frac{4}{7}$ times as much as the Plant was augmented.

*Several* other Plants *were try'd, that did not thrive in* Water, *or succeed any better than the* Cataputia *foregoing: But*

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*But 'tis besides my purpose to give a particular* Account *of them here.*

(F, G.) *These Two Viols* were fill'd, the former (F) with *Rain*, the other with *Spring-water*, at the same time as those above-mention'd were; and stood as long as they did. But they had neither of them any Plant; my Design in these being only to inform my self, whether any Water exhaled out of the Glasses, otherwise than *thorow* the Bodies of the Plants. The Orifices of these two Glasses were cover'd with Parchment; each piece of it being perforated with an hole of the same bigness with those of the Viols above. In this I suspended a bit of Stick about the thickness of the Stem of one of the aforesaid Plants, but not reaching down to the Surface of the included Water. I put them in thus, that the Water in these might not have more Scope to evaporate than that in the other Viols. Thus they stood the whole 77 Days in the same Window with the rest; when, upon Examination, I found none of the Water in these wasted or gone off. Tho' I observed both in these, and the rest, especially after hot Weather, small Drops of Water, not unlike Dew, adhering to the Insides of the Glasses, that Part of them, I mean, that was above the Surface of the enclosed Water.

The Water in these two Glasses that had no Plants in them, at the end of the Experiment, exhibited a larger Quantity of terrestrial Matter than that in any of those that had the Plants in them did. The Sediment at the bottom of the Viols was greater; and the



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*Nubeculæ* diffus'd through the Body of the Water thicker. And of that which was in the others, some of it proceeded from certain small Leaves that had fallen from that part of the Stems of the Plants that was within the Water, wherein they rotted and dissolved. The terrestrial Matter in the Rain-water was finer than that in the Spring-water.

## *Anno* 1692.

The Glasses made use of in this, were of the same sort with those in the former Experiment; and cover'd over with Parchment in like manner. The Plants here were all *Spear-mint*; the most kindly, fresh, sprightly Shoots I could chuse. The Water, and the Plants were weigh'd as above; and the Viols set in a Line, in a South Window; where they stood from *June* 2d, to *July* 28. which was just 56 Days.

'(H.) *Hyde-park Conduit-water*, alone. The '*Mint* weighed, when put in, 127 Gr. when 'taken out, 255 Gr. The whole Quantity of 'Water expended upon this Plant, amounted 'to 14190 Gr.

'This was all along a very kindly Plant; 'and had run up to above two Foot in height. 'It had shot but one considerable collateral 'Branch; but had sent forth many and long 'Roots, from which sprung very numerous, 'tho' small and short, lesser Fibres. These les-'ser Roots came out of the larger on two oppo-'site sides, for the most part; so that each

'Root,

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'Root, with its *Fibrillæ*, appear'd not unlike 'a ſmall Feather. To theſe *Fibrillæ* adher'd 'pretty much terreſtrial Matter. In the Wa-'ter which was at laſt thick and turbid, was a 'green Subſtance reſembling a fine thin *Con-'ferva.*

'(I.) The *ſame Water*, alone. The *Mint* 'weigh'd, when put in, 110 Gr. when taken 'out, 249. Water expended, 13140 Gr.

'This Plant was as kindly as the former, 'but had ſhot no collateral Branches. Its 'Roots, the Water, and the green Subſtance, 'all much as in the former.

'(K.) *Hyde-Park, Conduit-water*, in which 'was diſſolved an Ounce and half of *Common 'Garden-earth.* The *Mint* weigh'd, when put 'in, 76 Gr. when taken out 244 Gr. Water 'expended, Gr. 10731.

'This Plant, tho' it had the Misfortune to 'be annoy'd with many ſmall Inſects that hap-'pened to fix upon it; yet had ſhot very con-'ſiderable collateral Branches; and at leaſt 'as many Roots as either that in H or I; 'which had a much greater Quantity of ter-'reſtrial Matter adhering to the Extremities 'of them. The ſame green Subſtance here, 'that was in the two preceding.

'(L.) *Hyde-Park Water*, with the ſame Quan-'ty of Garden-mould as in the former. The '*Mint* weigh'd, when put in, 92 Gr. when 'taken out 376 Gr. The Water expended 14950 Gr.

'This Plant was far more flouriſhing than 'any of the precedent; had ſeveral very con-



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'ſiderable collateral Branches, and very numerous Roots, to which terreſtrial Matter 'adhered very copiouſly.

'The Earth in both theſe Glaſſes was very ſenſibly and conſiderably waſted, and leſs 'than when firſt put in. The ſame ſort of 'green Subſtance here as in thoſe above.

'(M.) *Hyde-Park Water*, diſtilled off with a 'gentle Still. The *Mint* weigh'd, when put in, '114 Gr. when taken out 155. The Water 'expended, 8803 Gr.

'This Plant was pretty kindly; had two 'ſmall collateral Branches, and ſeveral Roots, 'tho' not ſo many as that in H or I, but as 'much terreſtrial Matter adhering to them 'as thoſe had. The Water was pretty thick; 'having very numerous ſmall terreſtrial Particles ſwimming in it, and ſome Sediment at 'the bottom of the Glaſs. This Glaſs had 'none of the green Matter above-mentioned, 'in it.

'(N.) The Reſidue of the Water, which remain'd in the *Still* after that in M, was di'ſtill'd off. It was very turbid, and as high'coloured (reddiſh) as ordinary Beer. The '*Mint* weigh'd, when put in, 81 Gr. when 'taken out, 175 Gr. Water expended, 4344 'Gr. This Plant was very lively; and had 'ſent out ſix collateral Branches, and ſeveral Roots.

(O.) *Hyde-Park Conduit-water*, in which was diſſolved a Drachm of Nitre. The Mint ſet in this ſuddenly began to wither and decay; and

and died in a few Days: As likewiſe did two more Sprigs, that were ſet in it, ſucceſſively. In another Glaſs I diſſolved an Ounce of good Garden-mould, and a Drachm of Nitre; and in a third, half an Ounce of Wood-aſhes, and a Drachm of Nitre; but the Plants in theſe ſucceeded no better than in the former. In other Glaſſes I diſſolved ſeveral other ſorts of Earths, Clays, Marles, and variety of Manures, *&c.* I ſet Mint in diſtill'd Mint-water; and other Experiments I made, of ſeveral kinds, in order to get Light and Information, what haſtened or retarded, promoted or impeded Vegetation; but theſe do not belong to the Head I am now upon.

(P.) *Hyde-Park Conduit-water.* In this I fix'd a Glaſs Tube about ten Inches long, the Bore about one ſixth of an Inch in Diameter, fill'd with very fine and white Sand, which I kept from falling down out of the Tube into the Viol, by tying a thin piece of Silk over that end of the Tube that was downwards. Upon Immerſion of the lower end of it into the Water, this by little and little aſcended quite to the upper Orifice of the Tube. And yet, in all the fifty ſix Days which it ſtood thus, a very inconſiderable Quantity of Water had gone off, *viz.* ſcarce twenty Grains; tho' the Sand continued moiſt up to the top 'till the very laſt. The Water had imparted a green Tincture to the Sand, quite to the very top of the Tube. And, in the Viol, it had precipitated a greeniſh Sediment, mix'd with black. To the bottom and ſides of the Tube, as far as 'twas immers'd in the Water, adher'd

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her'd pretty much of the green Substance described above. Other like Tubes I fill'd with Cotton, Lint, Pith of Elder, and several other porous Vegetable Substances; setting some of them in clear Water; others in Water tinged with Saffron, Cochinele, *&c.* And several other Trials were made, in order to give a mechanical Representation of the motion and distribution of the Juices in Plants; and of some other *Phænomena* observable in Vegetation, which I shall not give the Particulars of here, as being not of use to my present design.

(Q, R, S,) *&c.* Several Plants set in Viols, ordered in like manner as those above, in *October*, and the following colder months. These throve not near so much; nor did the Water ascend in nigh the quantity it did in the better Seasons, in which the before recited Trials were made.

## *Some Reflexions upon the foregoing Experiments.*

1. *In Plants of the same kind, the less they are in Bulk, the smaller the Quantity of the fluid Mass, in which they are set, is drawn off; the Dispendium of it, where, the Mass is of equal thickness, being pretty nearly proportioned to the Bulk of the Plant.* Thus that in the Glass mark'd A, which weig'd only 27 Gr. drew off but 2558 Grains of the Fluid; and that in B, which weigh'd only $28\frac{1}{4}$, took up but 3004 Gr. whereas that in H, which weigh'd

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weigh'd 127 Grains, spent 14190 Gr. of the Liquid Mass.

The Water seems to ascend up the *Vessels* of Plants, in much the same manner as up a Filtre; and 'tis no great wonder that a larger Filtre should draw off more Water than a lesser; or that a Plant that has more and larger Vessels, should take up a greater share of the Fluid in which it is set, than one that has fewer and smaller ones can. Nor do I note this as a thing very considerable in it self, but chiefly in regard to what I am about to offer beneath; and that it may be seen that, in my other Collations of Things, I made due Allowance for this Difference.

2. *The much greatest part of the fluid Mass, that is thus drawn off and convey'd into the Plants, does not settle or abide there; but passes through the pores of them, and exhales up into the Atmosphere.* That the Water in these Experiments ascended only through the Vessels of the Plants, is certain. The *Glasses* F and G, that had no Plants in them, tho' disposed of in like manner as the rest, remain'd at the End of the Experiment, as at first; and none of the Water was gone off. And that the greatest part of it flies off from the Plant into the Atmosphere, is as certain. The least Proportion of the Water expended, was to the Augment of the Plant, as 46 or 50 to 1. And in some the weight of the Water drawn off, was 100, 200, nay, in one above 700 times as much as the Plant had received of Addition.

This

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This so continual an Emission and Detachment of Water, in so great Plenty from the Parts of Plants, affords us a manifest reason why Countries that abound with Trees, and the larger Vegetables especially, should be very obnoxious to Damps, great Humidity in the Air, and more frequent Rains, than others that are more open and free. The great Moisture in the Air, was a mighty inconvenience and annoyance to those who first settled in *America*; which at that time was much overgrown with Woods and Groves. But as these were burnt and destroy'd, to make way for Habitation and Culture of the Earth, the Air mended and cleared up apace, changing into a Temper much more dry and serene than before.

Nor does this Humidity go off pure and alone; but usually bears forth with it many Parts of the same Nature with those whereof the Plant, through which it passes, consists. The *Crasser* indeed are not so easily born up into the Atmosphere; but are usually deposited on the Surface of the Flowers, Leaves, and other Parts of the Plants: Hence comes our Manna's, our Honeys, and other Gummous Exsudations of Vegetables. But the finer and lighter Parts are with greater ease sent up into the Atmosphere. Thence they are conveyed to our Organs of Smell, by the Air we draw in Respiration; and are pleasant or offensive, beneficent or injurious to us, according to the Nature of the Plants from whence they arise. And since these owe their Rise to the Water that ascends out of the Earth through the Bodies of Plants, we cannot be far to seek for

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for the Cause why they are more numerous in the Air, and we find a greater quantity of Odors exhaling from Vegetables, in warm, humid Seasons, than in any other whatever.

3. *A great part of the terrestrial Matter that is mix'd with the Water, ascends up into the Plant as well as the Water.* There was much more terrestrial Matter at the end of the Experiment, in the Water of the Glasses F and G, that had no Plants in them, than in those that had Plants. The *Garden-mould* dissolved in the Glasses K and L was considerably diminished, and carried off. Nay, the terrestrial and vegetable Matter was born up in the Tubes filled with Sand, Cotton, *&c.* in that Quantity, as to be evident even to Sense. And the Bodies in the Cavities of the other Tubes, that had their lower Ends immers'd in Water, wherein Saffron, Cochinele, *&c.* had been infused, were tinged with Yellow, Purple, *&c.*

If I may be permitted to look abroad a while, towards our Shores and Parts within the Verge of the Sea, these will present us with a large Scene of Plants, that, along with the Vegetable, take up into them meer mineral Matter also in great abundance. Such are our Sea-Purslains, the several of *Alga's*, of Sampires, and other marine Plants. These contain common Sea-salt, which is all one with the *Fossil*, in such plenty, as not only to be plainly distinguish'd on the Palate, but may be drawn forth of them in considerable quantity. Nay, there want not those who affirm, there are Plants found that will yield *Nitre*, and



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and other mineral Salts; of which indeed I am not so far satisfied, that I can depend on the Thing, and therefore give this only as an hint for Enquiry.

To go on with the vegetable Matter, how apt and how much disposed this, being so very fine and light, is to attend Water in all its Motions, and follow it into each of its Recesses, is manifest, not only from the Instances above alledg'd, but many others. Percolate it withal the Care imaginable: Filter it with never so many Filtrations, yet some terrestrial Matter will remain. 'Tis true, the Fluid will be thinner every time than other, and more disingaged of the said Matter; but never wholly free and clear. I have filtred Water thorough several wholly free and clear Sheets of thick Paper; and, after that, through very close fine Cloth twelve times doubled. Nay, I have done this over and over; and yet a considerable quantity of this Matter discover'd it self in the Water after all. Now if it thus pass Interstices, that are so very small and fine along with the Water, 'tis the less strange it should attend it in its passage through the Ducts and Vessels of Plants. 'Tis true, filtering and distilling of Water intercepts and makes it quit some of the Earthy Matter it was before impregnated withal: But then that which continues with the Water after this, is fine and light; and such consequently, as is in a peculiar manner fit for the Growth and Nourishment of Vegetables. And this is the Case of Rain-water. The Quantity of terrestrial Matter it bears up into the Atmosphere, is not great.

But

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But that which it does bear up, is mainly of that light kind of vegetable Matter; and that too perfectly diſſolved, and reduced to ſingle Corpuſcles, all fit to enter the Tubules and Veſſels of Plants: On which Account 'tis that this Water is ſo very fertile and prolifick.

The Reaſon, why in this Propoſition, I ſay, only a great part of the terreſtrial Matter that is mix'd with the Water, aſcends up with it into the Plant, is, becauſe all of it cannot. The mineral Matter is a great deal of it, not only groſs and ponderous, but ſcabrous and inflexible; and ſo not diſpoſed to enter the Pores of the Roots. And a great many of the ſimple vegetable Particles by degrees unite, and form ſome of them ſmall Clods or *Molecula*; ſuch as thoſe mention'd in H, K, and L, ſticking to the Extremities of the Roots of thoſe Plants. Others of them intangle in a looſer manner; and form the *Nubecula*, and green Bodies, ſo commonly obſerved in ſtagnant Water. Theſe, when thus conjoin'd, are too big to enter the Pores, or aſcend up the Veſſels of Plants, which ſingly they might have done. They who are converſant in Agriculture, will eaſily ſubſcribe to this. They are well aware that, be their Earth never ſo rich, ſo good, and ſo fit for the Production of Corn or other Vegetables, little will come of it, unleſs the Parts of it be ſeparated and looſe. 'Tis on this Account they beſtow the Pains they do in Culture of it, in Digging, Plowing, Harrowing, and Breaking of the Clodded Lumps of Earth. 'Tis the ſame way that Sea-ſalt, Nitre, and

other

other Salts promote Vegetation. I am sorry I cannot subscribe to the Opinion of those Learned Gentlemen, who imagine Nitre to be essential to Plants; and that nothing in the vegetable Kingdom is transacted without it. By all the Trials I have been able to make, the thing is quite otherwise; and when contiguous to the Plant, it rather destroys than nourishes it. But this Nitre and other Salts certainly do; they loosen the Earth, and separate the concreted Parts of; by that means fitting and disposing them to be assumed by the Water, and carried up into the Seed or Plant, for its Formation and Augment. There's no Man but must observe, how apt all sorts of Salts are to be wrought upon by Moisture; how easily they liquate and run with it; and when these are drawn off, and have deserted the Lumps wherewith they were incorporated, those must moulder immediately, and fall asunder of Course. The hardest Stone we meet with, if it happen, as frequently it does, to have any sort of Salt intermix'd with the Sand of which it consists, upon being expos'd to an humid Air, in a short time dissolves and crumbles all to pieces; and much more will clodded Earth or Clay, which is not of near so compact and solid a Constitution as Stone is. The same way likewise is Lime serviceable in this Affair. The Husbandmen say of it, that it does not fatten, but only mellows the Ground: By which they mean, that it does not contain any thing in it self that is of the same Nature with the vegetable Mould, or afford any Matter fit for the Formation of Plants; but meerly

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meerly ſoftens and relaxes the Earth; by that means rendering it more capable of entering the Seeds and Vegetables ſet in it, in order to their Nouriſhment, than otherwiſe it would have been. The Properties of Lime are well known; and how apt 'tis to be put into Ferment and Commotion by Water. Nor can ſuch Commotion ever happen when Lime is mix'd with Earth, however hard and clodded that may be, without opening and looſening of it.

4. *The Plant is more or leſs nouriſh'd and augmented, in proportion as the Water, in which it ſtands, contains a greater or ſmaller Quantity of proper terreſtrial Matter in it.* The Truth of this Propoſition is ſo eminently diſcernible through the whole Proceſs of theſe Trials, that I think no doubt can be made of it. The *Mint* in the Glaſs C was of much the ſame Bulk and Weight with thoſe in A and B. But the Water, in which that was, being River-water, which was apparently ſtored more copiouſly with terreſtrial Matter, than the Spring or Rain-water, wherein they ſtood, were; it had thriven to almoſt double the Bulk that either of them had, and with a leſs Expence of Water too. So likewiſe the Mint in L, in whoſe Water was diſſolved a ſmall quantity of good Garden-mould, tho' it had the diſadvantage * to be leſs, when firſt ſet, than either of the Mints in H or I, whoſe Water was the very ſame with this in L, but had none of that Earth mix'd with it; yet, in a ſhort time the Plant

* *Confer. Prop.* 1. *ſupra.*



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not only overtook, but much out-ſtripp'd thoſe, and at the end of the Experiment was very conſiderably bigger and heavier than either of them. In like manner the *Mint* in N, tho' leſs at the beginning than that in M, being ſet in that thick, turbid, feculent Water, that remained behind, after that, wherein M was placed, was ſtill'd off, had in fine more than doubled its original weight and bulk; and received above twice the additional Encreaſe, than that in M, which ſtood in the thinner diſtill'd Water, had done. And, which is not leſs conſiderable, had not drawn off half the Quantity of Water that that had.

Why, in the beginning of this Article, I limit the Proportion of the Augment of the Plant to the Quantity of proper terreſtrial Matter in the Water, is, becauſe all, even the vegetable Matter, to ſay nothing of the Mineral, is not proper for the Nouriſhment of every Plant. There may be, and doubtleſs are, ſome Parts in different Species of Plants, that may be much alike, and ſo owe their Supply to the ſame common Matter; but 'tis plain all cannot. And there are other Parts ſo differing, that 'tis no ways credible they ſhould be form'd all out of the ſame ſort of Corpuſcles. So far from it, that there want not good Indications, as we ſhall ſee by and by, that every kind of Vegetable requires a peculiar and ſpecifick Matter for its Formation and Nouriſhment. Yea, each Part of of the ſame Vegetable does ſo; and there are very many and different Ingredients go to the Compoſition of the ſame individual Plant.

If

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If therefore the Soil, wherein any Vegetable or Seed is planted, contains all or most of those Ingredients, and those in due quantity, 'twill grow and thrive there; otherwise 'twill not. If there be not as many sorts of Corpuscles as are requisite for the Constitution of the main and more essential Parts of the Plant, 'twill not prosper at all. If there be these, and not in sufficient Plenty, 'twill starve, and never arrive to its natural Stature: Or if there be any the less necessary and essential Corpuscles wanting, there will be some Failure in the Plant; 'twill be defective in Taste, in Smell, in Colour, or some other way. But tho' a Tract of Land may happen not to contain Matter proper for the Constitution of some one peculiar kind of Plant; yet it may for several others, and those much differing among themselves. The vegetative Particles are commix'd and blended in the Earth, with all the diversity and variety, as well as all the uncertainty conceivable. I have given some Intimations of this elsewhere †, and shall not repeat them here, but hope in due time to put them into a much better Light than that they there stand in.

† *Nat. Hist. Earth*, p. 228. & seq.

It is not possible to imagine, how one uniform, homogeneous Matter, having its Principles or Original Parts all of the same Substance, Contexture, Magnitude, Figure, and Gravity, should ever constitute Bodies so egregiously unlike, in all those respects, as Vegetables of different kinds are; nay, even as the different Parts of the same Vegetable. That one should carry a resinous, another a

milky, a third a yellow, a fourth a red Juice, in its Veins; one afford a fragrant, another an offenſive Smell; one be ſweet to the Taſte, another bitter, acid, acerbe, auſtere, *&c.* that one ſhould be nouriſhing, another poiſonous, one purging, another aſtringent: In brief, that there ſhould be that vaſt difference in them, in their ſeveral Conſtitutions, Makes, Properties, and Effects, and yet all ariſe from the very ſame ſort of Matter, would be very ſtrange. And, to note by the by, this Argument makes equally ſtrong againſt thoſe, who ſuppoſe meer Water the Matter out of which all Bodies are form'd.

The *Cataputia* in the Glaſs E received but very little Encreaſe, only three Grains and an half all the while it ſtood, tho' 2501 Grains of Water were ſpent upon it. I will not ſay the reaſon was, becauſe that Water did not contain in it Matter fit and proper for the Nouriſhment of that peculiar and remarkable Plant. No, it may be the Water was not a proper *Medium* for it to grow in; and we know there are very many Plants that will not thrive in it. Too much of that Liquor, in ſome Plants, may probably hurry the terreſtrial Matter thorough their Veſſels too faſt for them to arreſt and lay hold of it. Be that as it will, 'tis moſt certain there are peculiar Soils that ſuit particular Plants. In *England*, Cherries are obſerved to ſucceed beſt in *Kent*; Apples in *Herefordſhire*; Saffron in *Cambridgeſhire*; Wood in two or three of our *Midland Counties*; and Teazles in *Somerſetſhire*. This is an Obſervation that hath held in all Parts, and indeed in all Ages of

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the World. The most ancient Writers of Husbandry * took notice of it; and are not wanting in their Rules for making choice of Soils suited to the Nature of each kind of Vegetable they thought valuable, or worth propagating.

* *Vid. Varronem, Columellam, & reliquos Rei Rusticæ Scriptores.*

But, which is a further Proof of what I am here endeavouring to advance, that Soil that is once proper and fit for the Production of some one sort of Vegetable, does not ever continue to be so. No, in Tract of time it loses that Property; but sooner in some Lands, and later in others: This is what all who are conversant in these things know very well. If Wheat, for Example, be sown upon a Tract of Land that is proper for that Grain, the first Crop will succeed very well; and perhaps the second, and the third, as long as the Ground is in Heart, as the Farmers speak; but in a few Years 'twill produce no more, if sowed with that Corn: Some other Grain indeed it may, as Barly. And after this has been sown so often, that the Land can bring forth no more of the same, it may afterwards yield good Oats; and, perhaps, Pease after them. At length 'twill become barren; the vegetative Matter, that at first it abounded withal, being educed forth of it by those successive Crops, and most of it born off. Each sort of Grain takes forth that peculiar Matter that is proper for its own Nourishment. First, the Wheat draws off those Particles that suit the Body of that Plant; the rest lying all quiet and undisturbed the while. And



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when the Earth has yielded up all them, those that are proper for Barly, a different Grain, remain still behind, 'till the successive Crops of that Corn fetch them forth too. And so the Oats, and Pease, in their Turn; 'till in fine all is carried off, and the Earth in great measure drain'd of that sort of Matter.

After all which, that very Tract of Land may be brought to produce another Series of the same Vegetables; but never 'till 'tis supplied with a new Fund of Matter, of like sort with that it at first contain'd. This Supply is made several ways: By the Grounds lying fallow for some time, 'till the Rain has pour'd down a fresh Stock upon it: Or, by the Tiller's Care in manuring of it. And for farther Evidence that this Supply is in reality of like sort, we need only reflect a while upon those Manures that are found by constant experience best to promote Vegetation, and the Fruitfulness of the Earth. These are chiefly either parts of Vegetables, or of Animals; which indeed either derive their own Nourishment immediately from vegetable Bodies, or from other Animals that do so. In particular, the Blood, Urine, and Excrements of Animals; Shavings of Horns, and of Hoofs; Hair, Wool, Feathers; calcin'd Shells; Lees of Wine, and of Beer; Ashes of all sorts of vegetable Bodies; Leaves, Straw, Roots, and Stubble, turn'd into the Earth by plowing or otherwise, to rot and dissolve there: These, I say, are our best Manures; and, being vegetable Substances, when refunded back again into the Earth, serve for the Formation of other like Bodies.

Not

Not wholly to confine our Thoughts to the Fields, let us look a while into our Gardens; where we shall meet with still further Confirmations of the same thing. The Trees, Shrubs, and Herbs cultivated in these, after they have continued in one Station, 'till they have derived thence the greater part of the Matter fit for their Augment, will decay and degenerate, unless either fresh Earth, or some fit Manure, be applied unto them. 'Tis true, they may maintain themselves there for some time, by sending forth Roots further and further to a great extent all round, to fetch in more remote Provision; but at last all will fail; and they must either have a fresh Supply brought to them, or they themselves be removed and transplanted to some Place better furnished with Matter for their Subsistence. And accordingly *Gardiners* observe, that Plants that have stood a great while in a Place, have longer Roots than usual; part of which they cut off, when they transplant them to a fresh Soil, as now not of any further use to them. All these Instances, to pass over a great many others that might be alledged, point forth a particular terrestrial Matter, and not Water, for the Subject to which Plants owe their Increase. Were it Water only, there would be no need of Manures; or of transplanting them from place to place. The Rain falls in all Places alike; in this Field and in that indifferently; in one side of an Orchard or Garden, as well as another. Nor could there be any reason, why a Tract of Land should yield Wheat one Year, and not the next; since the Rain showers down alike in each. But I am

sensible I have carried on this Article to too great a length; which yet on so ample and extensive a Subject, 'twas not easie to avoid.

5. *Vegetables are not form'd of Water; but of a certain peculiar Terrestrial Matter.* It hath been shewn, that there is a considerable Quantity of this Matter contain'd both in Rain, Spring, and River-water: That the much greatest part of the fluid Mass that ascends up into Plants, does not settle or abide there, but passes through the Pores of them, and *exhales* up into the Atmosphere: That a great part of the terrestrial Matter, mix'd with the Water, passes up into the Plant along with it; and that the Plant is more or less augmented in proportion, as the Water contains a greater or smaller Quantity of that Matter. From all which we may very reasonably infer, that *Earth, and not Water, is the Matter that constitutes Vegetables.* The Plant in E drew up into it 2501 Grains of the fluid Mass; and yet had received but Gr. 3 and a half of Increase from all that. The Mint in L, tho' it had at first the disadvantage to be much less than that in I; yet being set in Water wherewith Earth was plentifully mix'd, and *that* in I *only in Water* without any such additional Earth, it had vastly outgrown the other, weighing at last 145 Gr. more than that did, and so having gain'd about twice as much as that had. In like manner that in K, tho' 'twas a great deal less than when put in that in I, and also was impair'd and offended by Insects; yet being planted in Water wherein Earth was dissolved, whereas the Water in which it stood

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stood had none, it not only over-took, but considerably surpass'd the other; weighing at last 29 Gr. more than that in I, and yet had not expended so much Water as that by above 2400 Gr. The Plant in N, tho' at first a great deal less than that in M; yet being set in the foul crass Water that was left in the Still, after that, in which M was set, was drawn off, in Conclusion had gain'd in weight above double what that in the finer and thinner Water had. The Proportion of the Augment of that Plant that throve most was, to the fluid Mass spent upon it, but as 1 to 46. In others, 'twas but as 1 to 60, 100, 200; nay, in the Cataputia, 'twas but as 1 to 714. The Mint in B took up 39 Gr. of Water a-day, one day with another; which was much more than the whole weight of the Plant originally; and yet, with all this, it gain'd not one fourth of a Grain a-day in weight. Nay, that in H took up 253 Gr. a-day of the Fluid: which was near twice as much as its original weight, it weighing, when first set in the Water, but 127 Grains. And, after all, the daily Encrease of the Plant was no more than Gr. $2\frac{1}{16}$.

6. *Spring, and Rain-water, contain pretty near an equal Charge of vegetable Matter; River-water more than either of them.* The Plants in the Glasses A, B, and C, were at first of much the same size and weight. At the End of the Experiment, the Mint in A had gain'd 15 Gr. out of 2558 Gr. of Spring-water; that in B, Gr. 17 and an half, out of 3004 Gr. of Rain-water; but that in C had got 26 Gr. out of only

onis 2493 Gr. of River-water. I do not found this Proposition solely upon these Trials; having made some more, which I do not relate here, that agree well enough with these. So that the Proportions here delivered, will hold for the main; but a strict and just Comparison is hardly to be expected. So far from it, that I make no doubt, but the Water that falls in Rain, at some times, contains a greater share of terrestrial Matter than that which falls at others. A more powerful and intense Heat must needs hurry up a larger quantity of that Matter along with the humid Vapors that form Rain, than one more feeble and remiss ever possibly can. The Water of one Spring may flow forth with an higher Charge of this Matter, than that of another; this depending partly upon the quickness of the Ebullition of the Water, and partly upon the Quantity of that Matter latent in the *Strata*, through which the Fluid passes, and the greater or less laxity of those *Strata*. For the same reason, the Water of one River may abound with it more than that of another. Nay, the same River, when much agitated and in commotion, must bear up more of it, than when it moves with less rapidity and violence. That there is a great quantity of this Matter in Rivers; and that it contributes vastly to the ordinary Fertility of the Earth, we have an illustrious Instance in the *Nile*, the *Ganges*, and other Rivers that yearly overflow the neighbouring Plains. Their Banks shew the fairest and largest Crops of any in the whole World. They are even loaded with the multitude of their Productions; and

those

thoſe who have not ſeen them, will hardly be induced to believe the mighty Returns thoſe Tracts make in compariſon of others, that have not the Benefit of like Innundations.

7. *Water ſerves only for a Vehicle to the terreſtrial Matter, which forms Vegetables; and does not it ſelf make any addition unto them.* Where the proper terreſtrial Matter is wanting, the Plant is not augmented, tho' never ſo much Water aſcend into it. The *Cataputia* in E took up more Water than the Mint in C, and yet had grown but very little, having received only three Grains and an half of additional weight; whereas the other had received no leſs than twenty ſix Grains. The Mint in I was planted in the ſame ſort of Water as that in K was; only the latter had Earth diſſolved in the Water; and yet that drew off 13140 Gr. of the Water, gaining it ſelf no more than 139 Gr. in weight; whereas the other took up but 10731 Gr. of the Water, and was augmented 168 Gr. in weight. Conſequently that ſpent 2409 Gr. more of the Water than this in K did, and yet was not ſo much encreaſed in weight as this by 29 Gr. The Mint in M ſtood in the very ſame kind of Water as that in N did. But the Water in M having much leſs terreſtrial Matter in it than that in N had, the Plant bore up 8803 Gr. of it, gaining it ſelf only 41 Gr. the while; whereas that in N drew off no more than 4344 Gr. and yet was augmented 94 Gr. So that it ſpent 4459 Gr. of Water more than that did; and yet was not it ſelf ſo much in-

creaſed

creaſed in weight, as that was by 53 Gr. This is both a very fair, and a very concluſive Inſtance; on which Account 'tis that I make oftner uſe of it. Indeed they are all ſo; and to add any thing further on this Head, will not be needful.

'Tis evident therefore Water is not the Matter that compoſes Vegetable Bodies. 'Tis only the Agent that conveys that Matter to them; that introduces and diſtributes it to their ſeveral Parts for their Nouriſhment. That Matter is ſluggiſh and unactive, and would lye eternally confin'd to its Beds of Earth, without ever advancing up into Plants, did not Water, or ſome like Inſtrument, fetch it forth and carry it unto them. That therefore there is that plentiful Proviſion, and vaſt Abundance of it ſupplied to all Parts of the Earth, is a mark of a natural Providence ſuperintending over the Globe we inhabit; and ordaining a due Diſpenſation of that Fluid, without the Miniſtry of which the Noble Succeſſion of Bodies we behold, *Animals*, *Vegetables*, and *Minerals*, would be all at a ſtand †. But to keep to Plants, 'tis manifeſt Water, as well on this, as upon the other Hypotheſis, is abſolutely neceſſary in the Affair of Vegetation; and it will not ſucceed without it: Which indeed gave occaſion to the Opinion, that Water it ſelf nouriſhed, and was changed into vegetable Bodies. They ſaw, tho' theſe were planted in a Soil never ſo rich, ſo happy, ſo advantageous, nothing came of it unleſs there was Water too in a conſiderable quantity

† *Conf. Nat. Hiſt. Earth*, p. 47. & ſeq. uti & p. 128, &c.

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quantity. And it must be allow'd Vegetables will not come on or prosper where that is wanting: But yet what those Gentlemen inferr'd thence, was not, we see, well grounded.

This Fluid is capacitated for the Office here assign'd it several ways: By the Figure of its Parts; which, as appears from many Experiments, is exactly and mathematically Spherical; their Surfaces being perfectly polite, and without any the least Inequalities. 'Tis evident, Corpuscles of such a Figure are easily susceptible of motion, yea, far above any others whatever; and consequently the most capable of moving and conveying other Matter, that is not so active and voluble. Then the Intervals of Bodies of that Figure are, with respect to their bulk, of all others the largest; and so the most fitted to receive and entertain foreign Matter in them. Besides, as far as the Trials hitherto made inform us, the constituent Corpuscles of Water are each singly consider'd absolutely solid; and do not yield to the greatest external Force. This secures their Figure against any Alteration; and the Intervals of the Corpuscles must be always alike. By the latter, 'twill be ever disposed to receive Matter into it; and by the former, when once received, to bear it on along with it. Water is further capacitated to be a Vehicle to this Matter, by the tenuity and fineness of the Corpuscles of which it consists. We hardly know any Fluid in all Nature, except Fire, whose constituent Parts are so exceeding subtle and small as those of Water are. They'll pass

Pores

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Pores and Interstices, that neither Air nor any other Fluid will. This enables them to enter the finest Tubes and Vessels of Plants, and to introduce the terrestrial Matter, conveying it to all Parts of them; whilst each, by means of Organs 'tis endowed with for the purpose, intercepts and assumes into it self such Particles as are suitable to its own Nature, letting the rest pass on through the common Ducts. Nay, we have almost every where Mechanical Instances of much the same Tenor. 'Tis obvious to every one how easily and suddenly Humidity, or the Corpuscles of Water sustained in the Air, pervade and insinuate themselves into Cords, however tightly twisted, into Leather, Parchment, Vegetable Bodies, Wood, and the like. This it is that fits them for *Hygrometers*; and to measure and determine the different quantities of Moisture in the Air, in different Places and Seasons. How freely Water passes and carries with it terrestrial Matter, through Filtres, Colatures, Distillations, *&c.* hath been intimated already.

8. *Water is not capable of performing this Office to Plants, unless assisted by a due Quantity of Heat; and this must concur, or Vegetation will not succeed.* The Plants that were set in the Glasses Q, R, S, *&c.* in *October*, and the following colder Months, had not near the quantity of Water sent up into them, or so great an additional Encrease by much, as those that were set in *June*, *July*, and the hotter. 'Tis plain Water has no power of moving it self; or rising to the vast height it does in the more tall

tall and lofty Plants. So far from this, that it does not appear from any Discovery yet made, that even its own Fluidity consists in the intestine motion of its Parts; whatever some otherwise very learned and knowing Persons may have thought. There's no need of any thing more, for solving all the *Phænomena* of Fluidity, than such a Figure and Disposition of the Parts, as Water has. Corpuscles of that make, and that are all absolutely Spherical, must stand so very tickle and nicely upon each other, as to be susceptible of every Impression; and, tho' not perpetually in motion, yet must be ever ready and liable to be put into it, by any the slightest Force imaginable. It is true, the Parts of Fire or Heat are not capable of moving themselves any more than those of Water; but they are more subtil, light, and active, than those are, and so more easily put into motion. In fine, 'tis evident and matter of Fact, that Heat does operate upon, and move the Water, in order to its carrying on the Work of Vegetation: But how 'tis agitated it self, and where the motion first begins, this is no fit Place to enquire.

That the Concourse of Heat in this Work is really necessary, appears, not only from the Experiments before us, but from all Nature; from our Fields and Forests, our Gardens and our Orchards. We see in *Autumn*, as the Sun's Power grows gradually less and less, so its Effects on Plants is remitted, and their Vegetation slackens by little and little. Its Failure is first discernible in Trees. These are raised highest above the Earth; and require

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quire a more intense Heat to elevate the Water, charged with their Nourishment, to the Tops and Extremeties of them. So that for want of fresh Support and Nutriment, they shed their Leaves, unless secured by a very firm and hardy Constitution indeed, as our *ever-Greens* are. Next the Shrubs part with theirs; and then the Herbs and lower Tribes; the Heat being at length not sufficient to supply even these, tho' so near the Earth, the Fund of their Nourishment. As the Heat returns the succeeding Spring, they all recruit again; and are furnish'd with fresh Supplies and Verdure: But first, those which are lowest and nearest the Earth, Herbs, and they that require a lesser degree of Heat to raise the Water with its Earthy Charge into them: Then the Shrubs and higher Vegetables in their Turns; and lastly, the Trees. As the Heat increases, it grows too powerful, and hurries the Matter with too great Rapidity thorough the finer and more tender Plants: These therefore go off, and decay; and others that are more hardy and vigorous, and require a greater share of Heat, succeed in their Order. By which Mechanism, provident Nature furnishes us with a very various and differing Entertainment; and what is best suited to each Season, all the Year round.

As the Heat of the several Seasons affords us a different Face of Things; so the several distant Climates shew different Scenes of Nature, and Productions of the Earth *. The Hotter Countries yield ordinarily the largest and tallest Trees; and those

* *Conf. Nat. Hist. Earth*, Pag. 267. & seq.

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those in too much greater variety than the colder ever do. Even those Plants which are common to both, attain to a much greater Bulk in the Southern than in the Northern Climes. Nay, there are some Regions so bleak and chill, that they raise no Vegetables at all to any considerable size. This we learn from *Greenland*, from *Island*, and other Places of like cold Site and Condition. In these no Tree ever appears; and the very Shrubs they afford, are few, little, and low.

Again, in the warmer Climates, and such as do furnish forth Trees and the larger Vegetables, if there happen a remission or diminution of the usual Heat, their Productions will be impeded and diminished in proportion. Our late Colder Summers have given us proof enough of this. For tho' the Heat we have had, was sufficient to raise the vegetative Matter into the lower Plants, into our Corns, our Wheat, Barly, Pease, and the like; and we have had plenty of Straw-berries, Rasberries, Currans, Goosberries, and the Fruits of such other Vegetables as are low and near the Earth: Yea, and a moderate store of Cherries, Mulberries, Plumbs, Filberts, and some others that grow somewhat at a greater Height; yet our Apples, our Pears, Walnuts, and the Productions of the taller † Trees have been fewer, and those not so kindly, so thoroughly ripen'd, and brought to that Perfection they

* *The Dwarf-Apple and Pear-trees have succeeded better. And indeed in Trees of the same kind, those that keep closest to the Earth always produce the most and best Fruit. For which Reason 'tis that the Gardiners check and restrain the Growth of their better Fruit-trees, and prevent their running up to too great a Height.*

were in the former more benign and warm Seaſons. Nay, even the lower Fruits and Grains have had ſome ſhare in the common Calamity; and fallen ſhort both in Number and Goodneſs of what the hotter and kinder Seaſons were wont to ſhew us. As to our Grapes, Abricots, Peaches, Nectarins, and Figs, being tranſplanted hither out of hotter Climes, 'tis the leſs wonder we have of late had ſo general a Failure of them.

Nor is it the Sun, or the ordinary emiſſion of the Subterranean Heat only, that promotes Vegetation; but any other indifferently, according to its Power and Degree: This we are taught by our Stoves, hot Beds, and the like. All Heat is of like kind; and where-ever is the ſame Cauſe, there will be conſtantly the ſame Effect. There's a Procedure in every part of Nature, that is perfectly regular and geometrical, if we can but find it out; and the further our Searches carry us, the more ſhall we have occaſion to admire this, and the better 'twill compenſate our Induſtry.

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## *An Account of the Meaſure of the thickneſs of Gold upon Gilt Wire; together with a Demonſtration of the exceeding Minuteneſs of the Atoms or conſtituent Particles of Gold; as it was read before the* R. Society, *by* E. Halley.

WHAT are the conſtituent parts of Matter, and how there comes to be ſo great a diverſity in the weight of Bodies, to all appearance equally ſolid and denſe, ſuch as are Gold and Glaſs, (whoſe ſpecifick Gravities are nearly as 7 to 1) ſeems a very hard Queſtion to thoſe that ſhall rightly conſider it: For from undoubted Experiment, Gravity is in all Bodies proportionable to the quantity of Matter in each; and there is no ſuch thing as a propenſion of ſome more, others leſs, towards the Earth's Center; ſince the Impediment of the Air being removed, all Bodies deſcend, be they never ſo looſe or compact in texture, with equal Velocity. It follows therefore, That there is 7 times as much Matter in Gold, as in a Piece of Glaſs of the ſame Magnitude; and conſequently, that at leaſt ſix parts of ſeven in the Bulk of of Glaſs, muſt be Pore or Vacuity: This ſome Favourers of the Atomical Philoſophy have



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endeavoured to ſolve, by ſuppoſing the primary or conſtituent Atoms of Gold to be much larger than thoſe of other Bodies, and conſequently the Pores fewer; whereas in other Bodies, the great multitude of the interſperſed Vacuities does diminiſh their Weights.

Being deſirous to examine this Notion of the Magnitude of Atoms of Gold, I bethought my ſelf of the extreme Ductility of that Metal, which is ſeen in the beating of it into Leaf, and above all in the drawing fine Gilt-wire, by means whereof, I believed I might moſt exactly obtain the true thickneſs of the Coat of Gold, that appears, even with the Microſcope, ſo well to repreſent Gold it ſelf, that not the leaſt point of Silver appears through it. In order to this, I inform'd my ſelf among the Wire-drawers, what Gold they us'd to their Silver; and they told me, that the very beſt double Gilt Wire was made out of Cylidrick Ingots, 4 Inches in Circumference, and 28 Inches long, which weigh 16 Pounds Troy; on theſe they beſtow 4 Ounces of Gold, that is, to every 48 Ounces of Silver one of Gold; and that two Yards of the ſuper-fine Wire weighs a Grain. Hence at firſt ſight it appear'd, that the length of 98 Yards is in weight 49 Grains, and that a ſingle Grain of Gold covers the ſaid 98 Yards, and that the 10000th part of a Grain is above $\frac{1}{3}$ of an Inch long; which yet may be actually divided into 10, and ſo the 100000th part of a Grain of Gold be viſible without a Microſcope. But being deſirous to compute the thickneſs of the Skin of Gold, by means of the ſpecifick Gravities of the Metals, *viz.*

Silver

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Silver $10\frac{1}{3}$, and Gold $18\frac{2}{3}$, I found the Diameter of ſuch Wire the $\frac{1}{386}$ part of an Inch, and its Circumference the $\frac{1}{1213}$ part; but the Gold in thickneſs no to exceed the $\frac{1}{134500}$ part of an Inch; whence it may be concluded, that the Cube of the hundreth part of an Inch would contain above 2433000000, (or the Cube of 1345) of ſuch Atoms. And it may likewiſe be marvelled at, that Gold being ſtretcht to ſo great a degree as is here demonſtrated, ſhould yet ſhew it ſelf of ſo even and united a Texture, as not to let the white Colour of the Silver under it appear through any the leaſt Pores; which argues, that even in this exceeding thinneſs very many of thoſe Atoms may ſtill lie one over the other: Which is a Conſideration may merit the Thoughts of this Honourable Society, as tending to examine that renowned Atomical Doctrine, which has of late much obtained among the Learned.



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## *An Account of the ſeveral Species of* Infinite Quantity, *and of the Proportions they bear one to the other, as it was read before the* Royal Society, *by.* E. Halley.

THAT all Magnitudes infinitely great, or ſuch as exceed any aſſignable Quantity, are equal among themſelves, though it it be vulgarly received for a Maxim, is not yet ſo common as it is erroneous; and the reaſon of the miſtake ſeems to be, That the Mind of Man, coming to contemplate the Extenſions of what exceeds the bounds of its Capacity, and of which the very Idea does include a negation of Limits; it comes to paſs that we acquieſce generally, and it ſuffices to ſay ſuch a Quantity is infinite.

But if we come more nearly to examine this Notion, we ſhall find, that there are really beſides infinite *Length* and infinite *Area*, no leſs than Three ſeveral ſorts of infinite Solidity; all of which are *Quantitates ſui generis*, having no more relation or proportion the one to the other, than a Line to a Plane, or a Plane to a Solid, or a Finite to an Infinite: But that among themſelves, each of thoſe Species of Infinites are in given Proportions, is what I now intend to make plain, if poſſible.

But

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But first, infinite Length, or a Line infinitely long, is to be considered either as beginning at a Point, and so infinitely extended one way, or else both ways from the same Point; in which case the one, which is a beginning Infinity, is the one half of the whole, which is the Summ of the beginning and ceasing Infinity; or, as I may say, of Infinity, *a parte ante* and *a parte post*: Which is analogous to Eternity in time or duration, in which there is always as much to follow as is past, from any point or moment of Time: Nor doth the Addition or Subduction of finite Length or Space of time alter the case either in Infinity or Eternity, since both the one or the other cannot be any part of the whole.

As to infinite *Surface* or *Area*, any right Line, infinitely extended both ways on an infinite Plane, does divide that infinite Plane into equal Parts; the one to the right, and the other to the left of the said Line: But if from any Point in such a Plane, two right Lines be infinitely extended, so as to make an Angle, the infinite Area, intercepted between those infinite right Lines, is to the whole infinite Plane, as the Arch of a Circle, on the Point of Concourse of those Lines, as a Centre, intercepted between the said Lines, is to the Circumference of the Circle; or as the Degrees of the Angle to the 360 Degrees of a Circle. For Example, two right Lines meeting at a right Angle do include, on an infinite Plane, a quarter part of the whole infinite Area of such a Plane.

But if so be, two parallel infinite Lines be supposed drawn on such an infinite Plain, the



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Area intercepted between them will be likewise infinite; but at the same time will be infinitely less, than that Space which is intercepted between two infinite Lines that are inclined, tho' with never so small an Angle; for that in the one Case, the given finite distance of the parallel Lines diminishes the Infinity in one Degree of Dimension; whereas in a Sector, there is Infinity in both Dimensions; and consequently, the Quantities are the one infinitely greater than the other, and there is no proportion between them.

From the same Consideration arise the Three several Species of infinite Space or Solidity, as has been said; for a Parallelepipide, or a Cylinder, infinitely long, is greater than any finite Magnitude how great soever; and all such Solids supposed to be formed on given Bases, are as those Bases, in proportion to one another. But if two of these three Dimensions are wanting, as in the space intercepted between two parallel Planes infinitely extended, and at a finite distance; or with infinite Length and Breadth, with a finite Thickness; All such Solids shall be as the given finite distances one to another: But these Quantities, tho' infinitely greater than the other, are yet infinitely less than any of those, wherein all the three Dimensions are infinite. Such are the Spaces intercepted between two inclined Planes infinitely extended; the Space intercepted by the Surface of a Cone, or the sides of a Pyramid likewise infinitely continued, *&c.* of all which notwithstanding, the Proportions one to another, and to the τὸ πᾶν or vast Abyss of infinite Space (where-

in

in is the *Locus* of all things that are or can be; or to the Solid of infinite Length, Breadth, and Thickneſs, taken all manner of ways) are eaſily aſſignable. For the Space between two Planes, is to the whole, as the Angle of thoſe Planes to the 360 Degrees of the Circle. As for Cones and Pyramids, they are as the Spherical Surface, intercepted by them, is to the Surface of the Sphere; and therefore Cones are as the verſed Sines of half their Angles, to the Diameter of the Circle: Theſe three ſorts of infinite Quantity are analogous to a Line, Surface and Solid, and after the ſame manner cannot be compared, or have any proportion the one to the other.

Beſides theſe, there are ſeveral other Species of infinite Quantity, ariſing from the Contemplation of Curves, and their Aſymptotes; which, by reaſon of the difficulty of the Subject, cannot be made ſo plain to moſt Readers: But what has been already ſaid, may be ſufficient to evince what we undertook to explain.

*An*

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## *An Account of Dr.* Robert Hook's *Invention of the Marine Barometer, with its Deſcription and Uſes, publiſhed by order of the R. Society, by* E. Halley, *R. S. S.*

SInce it was found that the *Torricellian Tube*, commonly called the *Mercurial Barometer*, by the riſing and falling of the *Quick-ſilver* therein, doth preſage the Changes of the Air, in relation to fair and foul Weather; upon ſeveral Years obſervation of it, it has been proved and adjuſted for that purpoſe by Dr. *Robert Hook*; and there have been by him many attempts to improve the Inſtrument, and render the Minute Diviſions on the Scale thereof more ſenſible. He alſo judging that it might be of great uſe at Sea, contrived ſeveral ways to make it ſerviceable on Board Ship; one of which he explained to the *R. Society* at their weekly Meeting in *Greſham College*, *January* 2. $166\frac{7}{8}$. ſince which time he hath further cultivated the Invention, and ſome Years ago produced before the ſaid *Society*, the Inſtrument I am now to deſcribe, which for its ſubtilty and uſefulneſs, ſeemeth to

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to ſurpaſs all other performances of the like Nature.

Till ſuch time as the Authors preſent Indiſpoſition will give him leave to beſtow freely his Thoughts on this Subject upon the Publick, it is the Opinion of the Society, that ſuch an account be given of this Contrivance, as may render it known, and recommend it to the Mariners uſe, for which it was principally intended.

The *Mercurial Barometer* requiring a perpendicular Poſture, and the *Quick-ſilver* vibrating therein with great violence upon any Agitation, is therefore uncapable of being uſed at Sea (though it hath lately been contrived to be made portable), ſo it remained to find out ſome other Principle, wherein the Poſition of the Inſtrument was not ſo indiſpenſably neceſſary: For this, all thoſe that uſe the Sea are obliged to the great facility Dr. *Hook* has always ſhewn, in applying Philoſophical Experiments to their proper uſes.

It is about forty Years ſince, that the *Thermometers* of *Robt. de Fluctibus*, depending on the Dilatation and Contraction of included Air by Heat and Cold, have been diſuſed, upon diſcovery that the Airs preſſure is unequal; that inequality mixing itſelf with the effects of the warmth of the Air in that Inſtrument. And inſtead thereof was ſubſtituted the ſeal'd *Thermometer*, including Spirit of Wine (firſt brought into *England*, out of *Italy*, by Sir *Robert Southwell*) as a proper Standard of the temper of the Air in relation to Heat and Cold; that Ætherial Spirit being of all the known Liquors the moſt ſuſceptible of Dilatation

tion and Contraction, eſpecially with a moderate degree of either Heat or Cold. Now this being allowed as a Standard, and the other *Thermometer* that includes Air being graduated with the ſame Diviſions, ſo as at the time when the Air was included, to agree with the Spirit-*Thermometer* in all the degrees of Heat and Cold, noting at the ſame time the preciſe height of the *Mercury* in the common Barometers: It will readily be underſtood, that whenſoever theſe two *Thermometers* ſhall agree, the preſſure of the Air is the ſame it was, when the Air was included and the Inſtrument graduated: That if in the Air-*Thermometer* the Liquor ſtand higher than the Diviſion marked thereon, correſponding with that on the Spirit-glaſs, it is an indication that there is a greater preſſure of the Air at that time, than when the Inſtrument was graduated. And the contrary is to be concluded when the Air-glaſs ſtands lower than the Spirit, *viz.* that then the Air is ſo much lighter, and the *Quick-ſilver* in the ordinary Barometer lower than at the ſaid time of Graduation.

And the ſpaces anſwering to an Inch of *Mercury* will be more or leſs, according to the quantity of Air ſo included, and the ſmallneſs of the Glaſs Cane, in which the Liquors riſes and falls, and may be augmented almoſt in any proportion, under that of the ſpecifick Gravity of the Liquor of the *Thermometer* to *Mercury*. So as to have a Foot or more for an Inch of *Mercury*, which is another great convenience.

It

It has been observed by some, that in long keeping this Instrument, the Air included either finds a means to escape, or deposites some Vapours mixt with it, or else for some other cause becomes less Elastick, whereby, in process of time, it gives the height of the *Mercury* somewhat greater than it ought; but this, if it should happen in some of them, hinders not the usefulness thereof, for that it may at any time very easily be corrected by experiment, and the rising and falling thereof are the things chiefly remarkable in it, the just height being barely a Curiosity.

In these parts of the World, long experience has told us, that the rising of the *Mercury* forebodes fair Weather after foul, and an Easterly or Northerly Wind; and that the falling thereof, on the contrary signifies Southerly or Westerly Winds, with Rain, or stormy Winds, or both; which latter it is of much more consequence to provide against at Sea than at Land; and in a Storm, the *Mercury* beginning to rise is a sure sign that it begins to abate, as has been experienced in high Latitudes both to the Northwards and Southwards of the Æquator.

The Form of this Instrument is shown in the Cut by Tab. 4. Fig. 1. wherein,

A B represents the Spirit-*Thermometer*, graduated from 0, or the freezing Point, through all the possible degrees of the Heat or Cold of the Air, at least in these Climates.

C D is the Air-*Thermometer*, graduated after the same manner with the like Degrees.



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## *A Discourse concerning the Proportional Heat of the Sun in all Latitudes, with the Method of collecting the same, as it was read before the Royal Society in one of their late Meetings.* By E. Halley.

THere having lately arisen some Discourse about that part of the Heat of Weather, simply produced by the Action of the Sun; and I having affirmed, that if that were considered, as the only Cause of the Heat of the Weather, I saw no reason, but that under the Pole the solstitial Day ought to be as hot as it is under the Æquinoctial, when the Sun comes vertical, or over the Zenith: For this reason, that for all the 24 Hours of that Day under the Pole, the Sun's Beams are inclined to the Horizon, with an Angle of $23\frac{1}{2}$ Degrees; and under the Æquinoctial, tho' he come vertical, yet he shines no more than 12 Hours, and is again 12 ~~Hours absent; and that for 5 Hours 8 Min.~~ of that 12 Hours, he is not so much elevated as under the Pole; so that he is not 9 of the whole 24 higher than 'tis there, and is 15 Hours lower. Now the simple Action of the Sun is, as all other Impulses or Stroaks, more

or

or less forceable, according to the *Sinus* of the Angle of Incidence, or to the Perpendicular let fall on the Plain, whence the vertical Ray (being that of the greatest Heat) being put *Radius*, the force of the Sun on the Horizontal Surface of the Earth will be to that, as the *Sinus* of the Sun's Altitude at any other time. This being allowed for true, it will then follow, that the time of the continuance of the Sun's shining being taken for a *Basis*, and the *Sines* of the Sun's Altitudes erected thereon as Perpendiculars, and a Curve drawn through the Extreamities of those Perpendiculars, the *Area* comprehended shall be proportionate to the Collection of the Heat of all the Beams of the Sun in that space of time. Hence it will follow, that under the Pole the Collection of all the Heat of a tropical Day, is proportionate to a Rectangle of the *Sine* of $23\frac{1}{2}$ *gr.* into 24 Hours or the Circumference of a Circle; that is, the *Sine* of $23\frac{1}{2}$ *gr.* being nearly 4 Tenths of *Radius*; as $\frac{8}{10}$ into 12 Hours. Or the Polar Heat is equal to that of the Sun containing 12 Hours above the Horizon, at 53 *gr.* height, than which the Sun is not 5 Hours more elevated under the Æquinoctial.

But that this Matter may the better be understood, I have exemplied it by a Scheme (*Tab.*4.*Fig.*2.) wherein the *Area Z G H H*, is equal to the *Area* of all the *Sines* of the Sun's Altitude under the Æquinoctial, erected on the respective Hours from Sun-rise to the Zenith; and the *Area* ♋ *H H* ♋ is in the same portion to the Heat of the same 6 Hours under the Pole on the Tropical Day; and ☉



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*H H Q*, is proportional to the collected Heat of 12 Hours, or half a Day under the Pole, which space ⊙ *H H Q* is visibly greater than the other *Area H Z G H*, by as much as the *Area H G Q* is greater than the *Area Z G* ⊙; which, that it is so, is visible to sight, by a great excess; and so much in proportion does the Heat of the 24 Hours Sun shine under the Pole, exceed that of the twelve Hours under the Æquinoctial: Whence, *Cæteris paribus*, it is reasonable to conclude, that were the Sun perpetually under the Tropick, the Pole would be at least as warm, as it is now under the Line itself.

But whereas the Nature of Heat is to remain in the Subject, after the Cause that heated is removed, and particularly in the Air; under the Æquinoctial, the twelve Hours absence of the Sun does very little still the Motion impressed by the past Action of his Rays, wherein Heat consists, before he arise again: But under the Pole the long absence of the ⊙ for 6 Months, wherein the extreamity of Cold does obtain, has so chilled the Air, that it is as it were frozen, and cannot, before the Sun has got far towards it, be any way sensible of his presence, his Beams being obstructed by thick Clouds, and perpetual Foggs and Mists, and by that Atmosphere of Cold, as the late Honourable Mr. *Boyl* was pleased to term it, proceding from the everlasting Ice, which in immense Quantities does chill the Neighbouring Air, and which the too soon retreat of the Sun leaves unthawed, to encrease again, during the long Winter that follows this short interval of Summer. But the differing

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differing Degrees of Heat and Cold in differing Places, depend in great measure upon the Accidents of the Neighbourhood of high Mountains, whose height exceedingly chills the Air brought by the Winds over them; and of the Nature of the Soil, which variously retains the Heat, particularly the Sandy, which in *Africa*, *Arabia*, and generally where such Sandy Deserts are found, do make the Heat of the Summer incredible to those that have not felt it.

In the prosecution of this first Thought, I have solved the Problem generally, *viz.* to give the proportional Degree of Heat, or the sum of all the *Sines* of the Sun's Altitude, while he is above the Horizon in any oblique Sphere, by reducing it to the finding of the Curve Surface of a Cylindrick Hoof, or of a given part thereof.

Now this Problem is not of that difficulty as appears at first sight, for in *Tab.* 4. *Fig.* 3. let the Cylinder ABCD be cut obliquely with the Ellipse BKDI, and by the Center thereof H, describe the Circle IKLM; I say, the Curve Surface IKLB is equal to the Rectangle of IK and BL, or of HK and 2 BL or BC: And if there be supposed another Circle, as NQPO, cutting the said Ellipse in the Points P, Q; draw PS, QR, parallel to the Cylinders Axe, till they meet with the aforesaid Circle IKLM in the Points R, S, and draw the Lines RTS, QVP bisected in T and V. I say again, that the Curve Surface RMSQDP is equal to the Rectangle of BL or MD and RS, or of 2 BL or AD and ST or VP; and the Curve Surface QNPD is equal to RS × MD---the Arch



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RMS $\times$ SP, or the Arch MS $\times$ 2 SP: Or it is equal to the Surface RMSQDP, ſubſtracting the Surface RMSQNP. So likewiſe the Curve Surface QBPO is equal to the ſum of the Surface RMSQDP or RS $\times$ MD, and of the Surface RLSQOP, or the Arch LS $\times$ 2 SP.

This is the moſt eaſily demonſtrated from the Conſideration, That the Cylindrick Surface IKLB is to the inſcribed Spherical Surface IKLE, either in the whole, or in its Analogous Parts, as the tangent BL is to the Arch EL, and from the Demonſtrations of *Archimedes de Sphæra & Cylindro, Lib.* 1. *Prop.* XXX. and XXXVII. XXXIIX. which I ſhall not repeat here, but leave the Reader the pleaſure of examining it himſelf; nor will it be amiſs to conſult Dr. *Barrow*'s Learned Lectures on that Book, Publiſhed at *London*, *Anno.* 1684, *viz. Probl.* IX. and the Corollaries thereof.

Now to reduce our Caſe of the Sum of all the *Sines* of the Sun's Altitude in a given Declination and Latitude to the aforeſaid Problem, let us conſider (*Tab.*4. *Fig.*4.) which is the *Analemma* projected on the Plain of the *Meridian*, Z the Zenith, P the Pole, HH the Horizon, æ æ the Æquinoctial, ♋ ♋, ♑ ♑ the two Tropicks, ♋ I the *Sine* of the Meridian Altitude in ♋; and equal thereto, but perpendicular to the Tropick, erect ♋ 1, and draw the Line T 1 interſecting the Horizon in T, and the Hour Circle of 6, in the Point 4, and 6.4 ſhall be equal to 6R, or to the *Sine* of the Altitude at 6: And the like for any other Point in the Tropick, erecting a Perpendicular thereat, terminated by the Line T 1: Through the Point 4 draw the Line 4 5 7 parallel

allel to the Tropick, and repreſenting a Circle equal thereto; then ſhall the Tropick ♋ ♋ in *Fig.* 4. anſwer to the Circle NOPQ, in *Fig.* 3. the Circle 457 ſhall anſwer the Circle IKLM, T 4 1 ſhall anſwer to the Elliptick Segment QIBKP, 6 R or 6 4 ſhall anſwer to SP, and 5 1 to BL, and the Arch ♋ T, to the Arch LS, being the ſemidiurnal Arch in that Latitude and Declination; the *Sine* whereof, tho' not expreſſible in *Fig.* 4. muſt be conceived as Analogous to the Line TS or UP in *Fig.* 3.

The Relation between theſe two Figures being well underſtood, it will follow from what precedes, That, *the ſum of the* Sines *of the Meridian Altitudes of the Sun in the two Tropicks, (and the like for any two oppoſite Parallels) being multiplied by the* Sine *of the ſemidiurnal Arch, will give an* Area *Analogous to the Curve Surface RMSQDP; and thereto adding in Summer, or ſubſtracting in Winter, the Product of the length of the ſemidiurnal Arch, (taken according to* Van Ceulen's *Numbers) into the difference of the above-ſaid* Sines *of the Meridian Altitude: The ſum in one caſe and difference in another ſhall be as the Aggregate of all the* Sines *of the Sun's Altitude, during his appearance above the Horizon; and conſequently of all his Heat and Action on the Plain of the Horizon in the propoſed Day.* And this may alſo be extended to the parts of the ſame Day; for if the aforeſaid Sum of the *Sines* of the Meridian Altitudes, be multiplied by half the ſum of the *Sines* of the Sun's Horary diſtance from Noon, when the Times are before and after Noon; or by half their difference, when both are on the ſame ſide of

the Meridian; and thereto in Summer, or therefrom in Winter, be added or ſubſtracted the Product of half the Arch anſwerable to the propoſed interval of Time, into the difference of the *Sines* of Meridian Altitudes, the ſum in one caſe and difference in the other, ſhall be proportional to all the Action of the Sun during that ſpace of time.

I fore-ſee it will be Objected, that I take the *Radius* of my Circle on which I erect my Perpendiculars always the ſame, whereas the Parallels of Declination are unequal; but to this I anſwer, that our ſaid Circular Baſes ought not to be Anologous to the Parallels, but to the Times of Revolution, which are equal in all of them.

It may perhaps be uſeful to give an Example of the Computation of this Rule, which may ſeem difficult to ſome. Let the Solſtitial Heat, in ♋ and ♑ be required at *London*, *Lat.* 51°. 32.

| | | | | |
|---|---|---|---|---|
| 38o-2'8 | *Co-Lat.* | | *Diff. Aſcen.* | 330:-1'1. |
| 23 -30 | *Decl.* ☉ | | *Arc. Semidi. æſtiv.* | 123-11. |
| 61 - 58 | *Sinus* = | ,882674 | *Arc. Semi. hyb.* | 56-49. *S.* 638923 |
| 14 - 58 | *Sinus* = | ,258257 | *Arc. æſtiv. menſ.* | 2,149955 |
| | *Summa* | 1,140931 | *Arc. hyb. menſura* | 991683 |
| | *Diff.* | ,624417 | | |

Then 1, 140931 in ,836923+, 624417 in 2, 149955=2, 29734. And 1, 140931 in 836929 ---,624417 in ,991638= 33895.

So that 2, 29734 will be as the Tropical Summers Days Heat, and 0, 33895 as the Action of the Sun in the Day of the Winter Solſtice.

After

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After this manner I computed the following Table for every tenth Degree of Latitude, to the Æquinoctial and Tropical Sun, by which an Estimate may be made of the intermediate Degrees.

| Lat. | Sun in ♈ ♎ | Sun in ♋ | Sun in ♑ |
|---|---|---|---|
| 0 | 20000 | 18341 | 18341 |
| 10 | 19696 | 20290 | 15834 |
| 20 | 18794 | 21737 | 13166 |
| 30 | 17321 | 22651 | 10124 |
| 40 | 15321 | 23048 | 6944 |
| 50 | 12855 | 22991 | 3798 |
| 60 | 10000 | 22773 | 1075 |
| 70 | 6840 | 23543 | 000 |
| 80 | 3473 | 24673 | 000 |
| 90 | 0000 | 25055 | 000 |

Those that desire more of the Nature of this Problem, as to the Geometry thereof, would do well to compare the XIII. *Prop. Cap.* V. of the Learned Treatise, *De Calculo Centri Gravitatis*, by the Reverend Dr. *Wallis*, Published *Anno.* 1670.

From this Rule there follow several Corollaries worth Note: As I. That the Æquinoctial Heat, when the Sun comes Vertical, is as twice the Square of *Radius*, which may be proposed as a Standard to compare with in all other Cases. II. That under the Æquinoctial, the Heat is as the *Sine* of the Sun's Declination. III, That in the Frigid Zones when the Sun sets not, the Heat is as the Circumfer-



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ence of a Circle into the *Sine* of the Altitude at 6. And consequently, that in the same Latitude these Aggregates of Warmth, are as the *Sines* of the Sun's Declinations; and in the same Declination of *Sol*, they are as the *Sines* of the Lat., and generally they are as the *Sines* of the Lat. into the *Sines* of Declination. IV. That the Æquinoctial Days Heat is every where as the Co-sine of the Latitude. V. In all places where the Sun sets, the difference between the Summer and Winter Heats, when the Declinations are contrary, is equal to a Circle into the *Sine* of the Altitude at six in the Summer Parallel, and consequently those differences are as the *Sines* of Latitude into, or multiplied by the *Sines* of Declination. VI. From the Table I have added, it appears, that the Tropical Sun under the Æquinoctial, has, of all others, the least Force. Under the Pole it is greater than any other Days Heat whatsoever, being to that of the Æquinoctial as 5 to 4.

From the Table and these Coralleries may a general *Idea* be conceived of the sum of all the Actions of the Sun in the whole Year, and that part of the Heat that arises simply from the Presence of the Sun be brought to a Geometrical Certainty: And if the like could be performed for Cold; which is something else than the bare Absence of the Sun, as appears by many Instances, we might hope to bring what relates to this part of *Meteorology* to a perfect Theory.

Con-

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## *Concerning the Diſtance of the fix'd Stars. By the Honourable* Francis Roberts, *Eſq; S. R. S.*

THE Ancient Aſtronomers, who had no other way of computing the Diſtances of the Heavenly Bodies, but by their Parallax to the Semi-diameter of the Earth; and being never able to diſcover any in the fix'd Stars, did from thence rightly enough infer, that their Diſtance was very great, and much exceeding that of the Planets, but could go no farther otherwiſe than by uncertain gueſs.

Since the *Pythagorean* Syſtem of the World has been revived by *Copernicus*, (and now by all Mathematicians accepted for the true one) there ſeemed ground to imagine that the Diameter of the Earth's Annual Courſe (which, according to our beſt Aſtronomers, is at leaſt 40000 times bigger than the Semi-diameter of the Earth) might give a ſenſible Parallax to the fix'd Stars, tho' the other could not, and thereby determine their Diſtance more preciſely.

But though we have a Foundation to build on ſo vaſtly exceeding that of the Ancients, there are ſome Conſiderations may make us ſuſpect that even this is not large enough for our purpoſe.

Monſieur

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Monſieur *Hugens* (who is very exact in his Aſtronomical Obſervations) tells us, he could never diſcover any viſible Magnitude in the fix'd Stars, though he uſed Glaſſes which magnified the apparent Diameter above 100 times.

Now, ſince in all likelyhood the fix'd Stars are Suns, (perhaps of a different Magnitude) we may as a reaſonable *Medium* preſume they are generally about the bigneſs of our Sun.

Let us then (for Example) ſuppoſe the Dog-Star to be ſo. The Diſtance from us to the Sun being about 100 times the Sun's Diameter (as is demonſtrable from the Sun's Diameter being 32 minutes) it is evident, that the Angle under which the Dog-Star is ſeen in Mr. *Hugens*'s Teleſcope, muſt be near the ſame with the Angle of its Parallax to the Sun's Diſtance, or Semi-diameter of the Earth's Annual Courſe; ſo that the Parallax to the whole Diameter, can be but double ſuch a quantity, as even to Mr. *Hugens*'s nice Obſervation is altogether inſenſible.

The Diſtance therefore of the fixt Stars ſeems hardly within the reach of any of our Methods to determine; but from what has been laid down, we may draw ſome Concluſions that will much illuſtrate the prodigious vaſtneſs of it.

1. That the Diameter of the Earth's Annual Orb (which contains at leaſt 160 millions of miles) is but as a Point in compariſon of it; at leaſt it muſt be above 6000 times the Diſtance of the Sun: For if a Star ſhould appear through the aforeſaid Teleſcope half a minute

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minute broad (which is a pretty sensible Magnitude) the true apparent Diameter would not exceed 18 3d minutes, which is less than the 6000th part of the apparent Diameter of the Sun, and consequently the Sun's Distance not the 6000th part of the Distance of the Star.

2. That could we advance towards the Stars 99 Parts of the whole Distance, and have only $\frac{1}{100}$ Part remaining, the Stars would appear little bigger to us than they do here; for they would shew no otherwise than they do through a Telescope, which magnifies an Hundred-fold.

3. That at least Nine Parts in Ten of the Space between us and the fixed Stars, can receive no greater Light from the Sun, or any of the Stars, than what we have from the Stars in a clear Night.

4. That Light takes up more time in travelling from the Stars to us, than we in making a *West-India* Voyage (which is ordinarily performed in six Weeks.) That a Sound would not arrive to us from thence in 50000 Years, nor a Cannon-bullet in a much longer time. This is easily computed, by allowing (according to Mr. *Newton*) Ten minutes for the Journey of Light from the Sun hither, and that a Sound moves about 1300 Foot in a Second.

*The*

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## *The Famous Mr.* Isaac Newton's *Theory of the* Moon.

THIS *Theory* which hath been long expected by all the true Lovers of *Astronomy*, was communicated from Mr. *Newton*, to Dr. *Gregory Astron.* Professor at *Oxford*, and by him published in his *Astron. Elem. Philos.* and *Geomet.* p. 336. From whence, as it was lately translated into *English*, I thought fit to insert it here.

By this Theory, what by all Astronomers was thought most difficult and almost impossible to be done, the Excellent Mr. *Newton* hath now effected; *viz.* to determine the Moon's Place even in her Quadratures, and all other Parts of her Orbit, besides the Syzygys, so accurately by Calculation, that the Difference between that and her true Place in the Heavens, shall scarce be two minutes, and is usually so small, that it may well enough be reckon'd only as a Defect in the Observation. And this Mr. *Newton* experienced by comparing it with very many Places of the Moon, observ'd by Mr. *Flamsteed*, and communicated to him.

The Royal Observatory at *Greenwich*, is to the West of the Meridian of *Paris*, 2 deg. 19 min. Of *Urainburgh*, 12 deg. 51 min. 30 seconds. And of *Gedanum*, 18 deg. 48 minutes.

The

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The mean Motions of the Sun and Moon, accounted from the Vernal Æquinox at the Meridian of *Greenwich*, I make to be as followeth.

The last Day of *December* 1680, at Noon, (*Old Stile*) the mean Motion of the Sun was 9 Sign, 20 deg. 34 min. 46 seconds. Of the Sun's Apogeum, was 3 S. 7 deg. 23 min. 30 sec.

The mean Motion of the Moon at that time, was 6 S. 1 deg. 35 min. 45 seconds. And of her Apogee, 8 S. 4 deg. 28 min. 5 seconds. Of the ascending Node of the Moon's Orbit, 5 S. 24 deg. 14 min. 35 seconds, *&c.*

And on the last Day of *December*, 1700. at Noon, the mean Motion of the Sun was 9 S. 20 deg. 43 min. 50 seconds. Of the Sun's Apogee, 3 S. 7 deg. 44 min. 30 seconds. The mean Motion of the Moon was 10 S. 15 deg. 19 min. 50 seconds. Of the Moon's Apogee, 11 S. 8 deg. 18 min. 20 seconds. And of her ascending Node, 4 S. 27 deg. 24 min. 20 seconds. For in 20 *Julian* Years, or 7305 Days, the Sun's Motion is 20 Revolut. 0 S. 0 deg. 9 min. 4 seconds. And the Motion of the Sun's Apogee, 21 min. 0 seconds.

The Motion of the Moon in the same time, is 247 Revolut. 4 S. 13 deg. 34 min. 5 seconds. And the Motion of the Lunar Apogee, is 2 Revolut. 3 S. 3 deg. 50 min. 15 seconds. And the Motion of her Node, 1 Revolut. 0 S. 26 deg. 50 min. 15 seconds.

All which Motions are accounted from the Vernal Æquinox: Wherefore if from them there be subtracted the Recession or Motion of the Æquinoctial Point, *in Antecedentia*, during that space, which is 16 min. 0 sec. there will

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will remain the Motions in reference to the fix'd Stars in 20 *Julian* Years; *viz.* the Sun's 19 Revol. 11 S. 29 deg. 52 min. 24 ſeconds. Of his Apogee, 4 min. 20 ſeconds. And the Moon's 247 Revol. 4 S. 13 deg. 17 min. 25 ſeconds. Of her Apogee, 2 Revol. 3 S. 3 deg. 33 min. 35 ſeconds. And of the Node of the Moon, 1 Revol. 0 S. 27 deg. 6 min. 55 ſeconds.

According to this Computation, the *Tropical Year* is 365 Days, 5 Hours, 48 Minutes, 57 Seconds. And the *Sydereal Year* is 365 Days, 6 Hours, 9 Minutes, 14 Seconds.

Theſe mean Motions of the Luminaries are affected with various Inequalities: Of which,

1. There are the Annual Equations of the aforeſaid mean Motions of the Sun and Moon, and of the Apogee and Node of the Moon.

The Annual Equation of the mean Motion of the Sun, depends on the Eccentricity of the Earth's Orbit round the Sun, which is $16\frac{1}{12}$ of ſuch Parts, as that the Earth's mean Diſtance from the Sun ſhall be 1000: Whence 'tis called the *Equation of the Centre*; and is, when greateſt, 1 deg. 56 min. 20 ſeconds.

The greateſt Annual Equation of the Moon's mean Motion, is 11 deg. 49 ſeconds; of her Apogee, 20 min. and of her Node, 9 minutes, 30 ſeconds.

And theſe four Annual Equations are always mutually proportional one to another: Wherefore when any of them is at the greateſt, the other three will alſo be greateſt; and when any one leſſens, the other

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ther three will alſo be diminiſhed in the ſame *Ratio*.

The Annual Equation of the Sun's Centre being given, the three other correſpending Annual Equations will be alſo given; and therefore a Table of that will ſerve for all. For if the Annual Equation of the Sun's Centre be taken from thence, for any Time, and be called P, and let $\frac{1}{10}$ P = Q, Q + $\frac{1}{60}$ Q = R, $\frac{1}{6}$ P = D, D + $\frac{1}{30}$ D = E, and D − $\frac{1}{30}$ D = 2 F; then ſhall the Annual Equation of the Moon's mean Motion for that time be R, that of the Apogee of the Moon will be E, and that of the Node F.

Only obſerve here, That if the Equation of the Sun's Centre be required to be added; then the Equation of the Moon's mean Motion muſt be ſubtracted, that of her Apogee muſt be added, and that of the Node ſubducted. And on the contrary, if the Equation of the Sun's Centre were to be ſubducted, the Moon's Equation muſt be added, the Equation of her Apogee ſubducted, and that of her Node added.

There is alſo an *Equation of the Moon's mean Motion*, depending on the Situation of her Apogee, in reſpect of the Sun; which is greateſt when the Moon's Apogee is in an Octant with the Sun, and is nothing at all when it is in the Quadratures or Syzygys. This Equation, when greateſt, and the Sun in *Perigæo*, is 3 min. 56 ſeconds. But if the Sun be in *Apogæo*, it will never be above 3 minutes 34 ſeconds. At other Diſtances of the Sun from the Earth, this Equation, when greateſt, is reciprocally as the Cube of ſuch Diſtance. But when

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when the Moon's Apogee is any where but in the *Octants*, this Equation grows leſs, and is moſtly at the ſame diſtance between the Earth and Sun, as the Sine of the double Diſtance of the Moon's Apogee, from the next Quadrature or Syzygy, to the Radius.

This is to be added to the Moon's Motion, while her Apogee paſſes from a Quadrature with the Sun to a Syzygy; but this is to be ſubtracted from it, while the Apogee moves from the Syzygy to the Quadrature.

There is moreover another *Equation of the Moon's Motion*, which depends on the Aſpect of the Nodes of the Moon's Orbit with the Sun: And this is greateſt, when her Nodes are in *Octants* to the Sun, and vaniſhes quite, when they come to their Quadratures or Syzygys. This Equation is proportional to the Sine of the double Diſtance of the Node from the next Syzygy, or Quadrature; and at greateſt, is but 47 ſeconds. This muſt be added to the Moon's mean Motion, while the Nodes are paſſing from their Syzygys with the Sun, to their Quadratures with him; but ſubtracted while they paſs from the Quadratures to the Syzygys.

From the Sun's true Place, take the equated mean Motion of the Lunar Apogee, as was above ſhew'd, the Remainder will be the Annual Argument of the ſaid Apogee. From whence the *Eccentricity of the Moon*, and the *ſecond Equation* of her Apogee may be compar'd after the manner following (*which takes place alſo in the Computation of any other intermediate Equations.*

Let

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Tab. 3. Fig. 6. Let T repreſent the Earth, T S a Right Line joining the Earth and Sun, T A C B a Right Line drawn from the Earth to the middle or mean Place of the Moon's Apogee, equated, as above: Let the Angle S T A be the Annual Argument of the aforeſaid Apogee, T A the leaſt Eccentricity of the Moon's Orbit, T B the greateſt. Biſect A B in G; and on the Centre C, with the Diſtance A C deſcribe a Circle A F B, and make the Angle B C F =to the double of the Annual Argument. Draw the Right Line T F, that ſhall be the Eccentricity of the Moon's Orbit; and the Angle B T F, is the ſecond Equation of the Moon's Apogee required.

In order to whoſe Determination, let the mean Diſtance of the Earth from the Moon, or the Semi-diameter of the Moon's Orbit, be 1000000; then ſhall its greateſt Eccentricity T B be 66782 ſuch Parts; and the leaſt T A, 43319. So that the greateſt Equation of the Orbit, *viz.* when the Apogee is in the Syzygys, will be 7 deg. 39 min. 30 ſeconds, or perhaps 7 deg. 40 min. (for I ſuſpect there will be ſome Alteration, according to the Poſition of the Apogee in *Cancer* or *Capricorn.*) But when it is Quadrate to the Sun, the greateſt Equation aforeſaid will be 4 deg. 57 min. 56 ſeconds; and the greateſt Equation of the Apogee, 12 deg. 15 min. 4 ſeconds.

Having from theſe Principles made a Table of the Equation of the Moon's Apogee, and of the Eccentricities of her Orbit to each degree of the Annual Argument, from whence the Eccentricity T F, and the Angle B T F (*viz.* the ſecond and principal Equation of



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the Apogee) may easily be had for any Time required; let the Equation thus found be added to the first Equated Place of the Moon's Apogee, if the Annual Argument be less than 90 degrees, or greater than 180 degrees, and less than 270; otherwise it must be subducted from it; and the Summ or Difference shall be the Place of the Lunar Apogee secondarily equated; which being taken from the Moon's Place equated a third time, shall leave the mean Anomaly of the Moon corresponding to any given Time. Moreover, from this mean Anomaly of the Moon, and the before-found Eccentricity of her Orbit, may be found (by means of a Table of Equations of the Moons Centre made to every degree of the mean Anomaly, and some Eccentricities, (*viz.* 45000, 50000, 55000, 60000, and 65000) the *Prostapharesis*, or Equation of the Moon's Centre, as in the common way: And this being taken from the former Semi-circle of the middle Anomaly, and added in the latter to the Moon's Place thus thrice equated, will produce the Place of the Moon a fourth time equated.

The greatest Variation of the Moon (*viz.* that which happens when the Moon is in an Octant with the Sun) is nearly, reciprocally as the Cube of the Distance of the Sun from the Earth. Let that be taken 37 min. 25 seconds, when the Sun is *in Perigæo*, and 33 min. 40 seconds, when he is *in Apogæo*: And let the Differences of this Variation in the Octants be made reciprocally, as the Cubes of the Distances of the Sun from the Earth; and so let a Table be made of the aforesaid Variation

tion of the Moon in her Octants (or its Logarithms) to every Tenth, Sixth, or Fifth Degree of the mean Anomaly: And for the Variation out of the Octants, make, as Radius to the Sine of the double Distance of the Moon from the next Syzygy, or Quadrature :: so let the afore-found Variation in the Octant be to the Variation congruous to any other Aspect; and this added to the Moon's Place before found in the first and third Quadrant (accounting from the Sun) or subducted from it in the second and fourth, will give the Moon's Place equated a fifth time.

Again, as Radius to the Sine of the Summ of the Distances of the Moon from the Sun, and of her Apogee from the Sun's Apogee (or the Sine of the Excess of that Summ above 360 deg.) :: so is 2 min. 10 seconds, to a sixth Equation of the Moon's Place, which must be subtracted, if the aforesaid Summ or Excess be less than a Semi-circle; but added, if it be greater. Let it be made also, as Radius to the Sine of the Moon's distance from the Sun :: so 2 deg. 20 secants, to a seventh Equation; which when the Moon's Light is increasing, add; but when decreasing, subtract; and the Moon's Place will be equated a seventh time, and this is her Place *in her proper Orbit*.

Not here, the Equation thus produced by the mean Quantity 2 degrees, 20 seconds, is not always of the same magnitude; but is increased and diminished, according to the Position of the Lunar Apogee. For if the Moon's Apogee be in Conjunction with the



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Sun's, the aforeſaid Equation is about 54 ſeconds greater: But when the Apogees are in oppoſition, 'tis about as much leſs; and it librates between its greateſt Quantity 3 minutes, 14 ſeconds, and its leaſt, 1 minute, 26 ſeconds. And this is, when the Lunar Apogee is in Conjunction, or Oppoſition with the Sun's: But in the Quadratures, the aforeſaid Equation is to be leſſen'd about 50 ſeconds, or one minute, when the Apogees of the Sun and Moon are in Conjunction; but if they are in Oppoſition, for want of a ſufficient number of Obſervations, I cannot determine, whether it is to be leſſen'd or increas'd. And even as to the Argument or Decrement of the Equation, 2 minutes, 20 ſeconds, above mentioned, I dare determine nothing certain, for the ſame Reaſon, *viz.* the want of Obſervation accurately made.

If the ſixth and ſeventh Equations are augmented or diminiſhed in a reciprocal *Ratio* of the diſtance of the Moon from the Earth; *i. e.* in a direct *Ratio* of the Moon's Horizontal Parallax, they will become more accurate: And this may be readily done, if Tables are firſt made to each minute of the ſaid Parallax, and to every ſixth or fifth degree of the Argument of the ſixth Equation for the Sixth, as of the diſtance of the Moon from the Sun, for the Seventh Equation.

From the Sun's Place, take the mean motion of the Moon's aſcending Node, equated as above; the Remainder ſhall be the Annual Argument of the Node, whence its ſecond Equation may be computed after the following manner in the preceding Figure.

Let

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Let T, as before, represent the Earth; T S a Right Line, conjoining the Earth and Sun: Let also the Line T A C B, be drawn to the Place of the ascending Node of the Moon, as above equated; and let S T A be the Annual Argument of the Node. Take T A from a Scale, and let it be to A B :: as 56 to 3, or as 11 $\frac{2}{3}$ to 1. Then bisect B A in C, and on C as a Centre, with the Distance C A, describe a Circle as A F B, and make the Angle B C F, equal to double the Annual Argument of the Node before-found: So shall the Angle B T F, be the second Equation of the ascending Node; which must be added, when the Node is passing from the Quadrature to a Syzygy with the Sun; and subducted, when the Node moves from a Syzygy towards a Quadrature. By which means, the true Place of the Node of the Lunar Orbit will be gained: Whence from Tables made after the common way, the *Moon's Latitude, and the Reduction of her Orbit to the Ecliptick*, may be computed, supposing the Inclination of the Moon's Orbit to the Ecliptick, to be 4 deg. 59 min. 35 seconds, when the Nodes are in Quadrature with the Sun; and 5 deg. 17 min. 20 seconds, when they are in the Syzygys.

And from the Longitude and Latitude thus found, and the given Obliquity of the Ecliptick, 23 degrees, 29 minutes, to the Right Ascension and Declination of the Moon will be found.

The Horizontal Parallax of the Moon, when she is in the Syzygys, at a mean distance from the Earth, I make to be 57 min. 30 seconds; and her Horary Motion, 33 min. 32



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seconds, 32 thirds; and her apparent Diameter 31 min. 30 seconds. But in her Quadratures at a mean Distance from the Earth, I make the Horizontal Parallax of the Moon to be 59 min. 40 seconds, her Horary Motion 32 min. 12 seconds, 2 thirds, and her apparent Diameter, 31 min. 3 seconds. The Moon in an Octant to the Sun, and at a mean distance, hath her Centre distant from the Centre of the Earth about 60 $\frac{2}{9}$ of the Earth's Semi-diameters.

The Sun's Horizontal Parallax I make to be 10 seconds, and its apparent Diameter at a mean distance from the Earth, I make 32 minutes, 15 seconds.

The Atmosphere of the Earth, by dispersing and refracting the Sun's Light, casts a Shadow, as if it were an Opake Body, at least to the height of 40 or 50 Geographical Miles (by a Geographical Mile, I mean the sixtieth part of a Degree of a great Circle, on the Earth's Surface.) This Shadow falling upon the Moon in a Lunar Eclipse, makes the Earth's Shadow be the larger or broader. And to each Mile of the Earth's Atmosphere, is correspondent a Second in the Moon's Disk, so that the Semi-diameter of the Earth's Shadow projected upon the Disk of the Moon, is to be increased about 50 seconds. Or, which is all one, in a Lunar Eclipse, the Horizontal Parallax of the Moon is to be increased in the Ratio of about 70 to 69.

Thus far the Theory of this Incomparable Mathematician. And if we had many Places of the Moon accurately observed, especially about her Quadratures, and these well com-

pared

Fig. 1

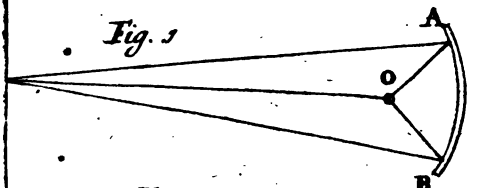
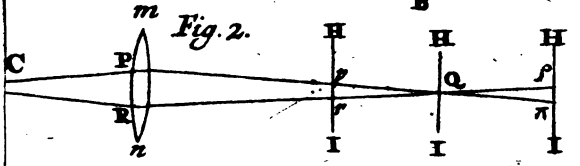



Fig. 2.



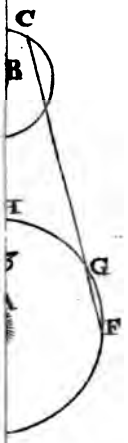
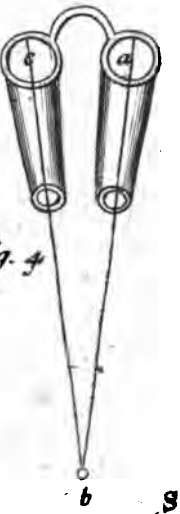




Fig. 4




5

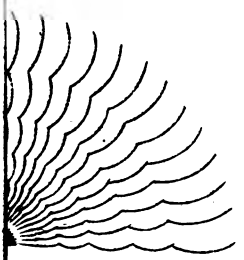
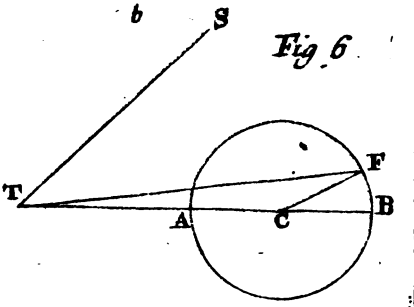


Fig. 6

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pared with her Places, at the same time calculated according to this Theory; it would then appear, whether there yet remain any other sensible Equations, which when accounted for, might serve to improve and enlarge this Theory.

## *An Estimate of the Degrees of the* Mortality *of Mankind, drawn from curious* Tables *of the* Births *and* Funerals *at the City of* Breslaw; *with an Attempt to ascertain the Price of* Annuities *upon* Lives. *By Mr.* E. Halley, *R.S.S.*

THE Contemplation of the *Mortality* of *Mankind*, has besides the *Moral*, its *Physical* and *Political* Uses, both which have been some Years since most judiciously considered by the curious Sir *William Petty*, in his *Natural* and *Political* Observations on the Bills of *Mortality* of *London*, owned by Captain *John Graunt*: And since in a like Treatise on the Bills of *Mortality* of *Dublin*. But the Deduction from those Bills of *Mortality* seemed even to their Authors to be defective: First, In that the *Number* of the People was wanting. Secondly, That the *Ages* of the People dying was not to be had. And Lastly, That both *London* and *Dublin*, by reason of the great and casual Accession of *Strangers* who die therein, (as appeared in both, by the great Excess of the *Funerals* above the *Births*) rendred them incapable of being Standards for this purpose; which requires, if it were

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were possible, that the People, we treat of, should not at all be changed, but die where they were born, without any adventitious Increase from Abroad, or Decay by Migration elsewhere.

This *Defect* seems in a great measure to be satisfied by the late curious Tables of the Bills of *Mortality* at the City of *Breslaw*, lately communicated to this Honourable Society by Mr. *Justell*, wherein both the Ages and Sexes of all that die are monthly delivered, and compared with the number of the *Births*, for Five Years last past, *viz.* 1687, 88, 89, 90, 91, seeming to be done with all the Exactness and Sincerity possible.

This City of *Breslaw* is the Capital City of the Province of *Silesia*; or, as the *Germans* call it, *Schlesia*, and is situated on the Western Bank of the River *Oder*, anciently called *Viadrus*, near the Confines of *Germany* and *Poland*, and very nigh the Latitude of *London*. It is very far from the Sea, and as much a *Mediterranean* Place as can be desired, whence the Confluence of Strangers is but small, and the Manufacture of Linnen employs chiefly the poor People of the Place, as well as of the Country round about; whence comes that sort of Linnen we usually call your *Schlesia Linnen*; which is the chief, if not the only Merchandize of the Place. For these Reasons, the People of this City seem most proper for a *Standard*; and the rather, for that the *Births* do, a small matter exceed the Funerals. The only thing wanting, is the Number of the whole People, which in some measure I have endeavour'd to supply, by the comparison



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parison of the *Mortality* of the People of all Ages, which I shall from the said Bills trace out with all the Accuracy possible.

It appears that in the Five Years mentioned, *viz.* from 87 to 91 inclusive, there were *born* 6193 Persons, and buried 5869; that is, born *per Annum* 1238, and *buried* 1174; whence an *Increase* of the People may be argued of 64 *per Annum*, or of about a 20th part, which may perhaps be balanced by the Levies for the *Emperor's* Service in his Wars. But this being contingent, and the Births certain, I will suppose the People of *Breslaw* to to be increased by 1238 *Births* annually. Of these it appears by the same Tables, that 348 do die *yearly* in the *first Year* of their *Age*, and that but 890 do arrive at a full *Year's Age*; and likewise, that 198 do die in the *Five Years* between 1 and 6 compleat, taken at a *Medium*; so that but 692 of the Persons *born* do survive *Six* whole *Years*. From this *Age* the Infants being arrived at some degree of Firmness, grow less and less *Mortal*; and it appears, that of the whole People of *Breslaw* there die *yearly*, as in the following Table, wherein the upper Line shews the *Age*, and the next under it, the *Number* of Persons of that Age *dying yearly*.

| | | |

thence the number of the Living being grown very ſmall, they gradually decline till there be none left to *die*; as may be ſeen at one View in the Table.

From theſe Conſiderations I have formed the *adjoined Table*, whoſe Uſes are manifold, and give a more juſt *Idea* of the *State* and *Condition* of *Mankind*, than any thing yet extant that I know of. It exhibits the *Number* of *People* in the City of *Breſlaw* of all Ages, from the *Birth* to extreme *Old Age*, and thereby ſhews the Chances of *Mortality* at all *Ages*, and likewiſe how to make a certain Eſtimate of the Value of *Annuities* for *Lives*, which hitherto has been only done by an imaginary *Valuation*: Alſo the *Chances* that there are that a *Perſon* of any *Age* propoſed does live to any other *Age* given; with many more, as I ſhall hereafter ſhew. This *Table* does ſhew the *Number* of Perſons that are living in the *Age* current annexed thereto, as follows:

Age.

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| Age. Curt. | Per- sons. | Age. Curt. | Per- sons. | Age. Curt. | Per- sons. | Age. Curt. | Per- sons. | Age. Curt. | Per- sons. | Age. Curt. | Per- sons. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1000 | 8 | 680 | 15 | 628 | 22 | 586 | 29 | 539 | 36 | 481 |
| 2 | 855 | 9 | 670 | 16 | 622 | 23 | 579 | 30 | 531 | 37 | 472 |
| 3 | 798 | 10 | 661 | 17 | 616 | 24 | 573 | 31 | 523 | 38 | 463 |
| 4 | 760 | 11 | 653 | 18 | 610 | 25 | 567 | 32 | 515 | 39 | 454 |
| 5 | 732 | 12 | 646 | 19 | 604 | 26 | 560 | 33 | 507 | 40 | 445 |
| 6 | 710 | 13 | 640 | 20 | 598 | 27 | 553 | 34 | 499 | 41 | 436 |
| 7 | 692 | 14 | 634 | 21 | 592 | 28 | 546 | 35 | 490 | 42 | 427 |
| Age. Curt. | Per- sons. | Age. Curt. | Per- sons. | Age. Curt. | sons. Per- | Age. Curt. | Per- sons. | Age. Curt. | Per- sons. | Age. Curt. | Per- sons. |
| 43 | 417 | 50 | 346 | 57 | 272 | 64 | 202 | 71 | 131 | 78 | 58 |
| 44 | 407 | 51 | 335 | 58 | 262 | 65 | 192 | 72 | 120 | 79 | 49 |
| 45 | 397 | 52 | 324 | 59 | 252 | 66 | 182 | 73 | 109 | 80 | 41 |
| 46 | 387 | 53 | 313 | 60 | 242 | 67 | 172 | 74 | 98 | 81 | 34 |
| 47 | 377 | 54 | 302 | 61 | 232 | 68 | 162 | 75 | 88 | 82 | 28 |
| 48 | 367 | 55 | 292 | 62 | 222 | 69 | 152 | 76 | 78 | 83 | 23 |
| 49 | 357 | 56 | 282 | 63 | 212 | 70 | 142 | 77 | 68 | 84 | 20 |

Thus

| Age. | Persons. |
|---|---|
| 7 | 5547 |
| 14 | 4584 |
| 21 | 4270 |
| 28 | 3964 |
| 35 | 3604 |
| 42 | 3178 |
| 49 | 2709 |
| 56 | 2194 |
| 63 | 1694 |
| 70 | 1204 |
| 77 | 692 |
| 84 | 253 |
| 100 | 107 |
| | 34000 |

Sum Total.

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Thus it appears, that the whole People of *Breslaw* does consist of 34000 *Souls*, being the Sum *Total* of the Persons of all Ages in the *Table*: The first use hereof is to shew the Proportion of *Men* able to bear *Arms* in any *Multitude*, which are those between 18 and 56, rather than 16 and 60; the one being generally too weak to bear the *Fatigues* of *War*, and the Weight of *Arms*; and the other too crasie and infirm from *Age*, notwithstanding particular Instances to the contrary. Under 18 from the *Table*, are found in this City 11997 Persons, and 3950 above 56, which together make 15947. So that the Residue to 34000 being 18053, are Persons between those *Ages*. At least one half thereof are Males, or 9027: So that the whole Force this City can raise of *Fencible Men*, as the *Scotch* call them, is about 9000, or $\frac{2}{4}$, or somewhat more than a quarter of the *Number* of *Souls*, which may perhaps pass for a Rule for all other places.

The *Second Use* of this *Table*, is, to shew the differing degrees of *Mortality*, or rather *Vitality* in all *Ages*; for if the number of Persons of any *Age* remaining after one Year, be divided by the difference between that and the number of the Age proposed, it shews the *odds* that there is, that a Person of that Age does not die in a *Year*. As for Instance, a Person of 25 *Years* of *Age* has the odds of 560 to 7, or 80 to 1, that he does not *die* in a *Year*: Because that of 567, living of 25 Years of Age, there do die no more than 7 in a *Year*, leaving 560 of 26 Years old.

So

So likewiſe for the *odds*, that any Perſon does not die before he attain any propoſed *Age*: Take the *number* of the remaining Perſons of the Age propoſed, and divide it by the difference between it and the number of thoſe of the *Age* of the Party propoſed; and that ſhews the *odds* there is between the Chances of the Party's living or dying. As for Inſtance; What is the *odds* that a Man of 40 lives 7 Years: Take the number of Perſons of 47 Years, which in the Table is 377, and ſubtract it from the number of Perſons of 40 Years, which is 445, and the *difference* is 68: Which ſhews that the *Perſons dying* in that 7 Years, are 68; and that it is 377 to 68, or 5½ to 1, that a Man of 40 does live 7 Years. And the like for any other *number* of *Years*.

*Uſe* III. But if it be enquired at what number of *Years*, it is an even Lay that a Perſon of any Age ſhall die, this Table readily performs it: For if the *number* of Perſons *living* of the *Age* propoſed, be *halfed*, it will be found by the *Table* at what Year the ſaid *Number* is reduced to half by *Mortality*; and that is the Age, to which it is an even Wager, that a Perſon of the *Age* propoſed ſhall arrive before he *die*. As for Inſtance; A Perſon of 30 Years of Age is propoſed, the number of that Age is 531, the half thereof is 265, which number I find to be between 57 and 58 Years; ſo that a Man of 30 may reaſonably expect to live between 27 and 28 Years.

*Uſe* IV. By what has been ſaid, the *Price* of *Inſurance* upon Lives ought to be regulated, and the difference is diſcovered between the

*Price*

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*Price* of inſuring the *Life* of a *Man* of 20 and 50. For Example; it being 100 to 1, that a Man of 20 dies not in a Year, and but 38 to 1, for a Man of 50 Years of Age.

*Uſe* V. On this depends the Valuation of *Annuities* upon *Lives*; for it is plain, that the *Purchaſer* ought to pay for only ſuch a part of the Value of the *Annuity*, as he has Chances that he is living; and this ought to be computed yearly, and the Sum of all thoſe yearly Values being added together, will amount to the Value of the *Annuity* for the *Life* of the Perſon propoſed. Now the preſent Value of Money payable after a Term of Years, at any given Rate of Intereſt, either may be had from Tables already computed; or almoſt as compendiouſly, by the Table of Logarithms: For the Arithmetical Complement of the Logarithm of Unity and its yearly Intereſt, (that is, of 1, 06 for Six *per Cent.* being 9, 974694.) being multiplied by the number of Years propoſed, gives the preſent Value of One Pound payable after the end of ſo many Years. Then by the foregoing Propoſition, it will be as the number of Perſons living after that Term of Years, to the number dead; ſo are the odds that any one Perſon is alive or dead. And by conſequence, as the Sum of both, or the number of Perſons living of the Age firſt propoſed, to the number remaining after ſo many Years, (both given by the Table) ſo the preſent Value of the yearly Sum payable after the Term propoſed, to the Sum which ought to be paid for the Chance the Perſon has to enjoy ſuch an Annuity after ſo many Years. And this being repeated for every

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every Year of the Person's Life, the Sum of all the present Values of those Chances is the true Value of the Annuity. This will without doubt appear to be a most laborious Calculation; but it being one of the principal Uses of this Speculation, and having found some *Compendia* for the Work, I took the pains to compute the following Table, being the short Result of a not ordinary number of Arithmetical Operations: It shews the Value of Annuities for every Fifth Year of Age, to the Seventieth, as follows.

| Age | Years Pur. | Age | Years Pur. | Age | Years Pur. |
|---|---|---|---|---|---|
| 1 | 10,28 | 25 | 12,27 | 50 | 9,21 |
| 5 | 13,40 | 30 | 11,72 | 55 | 8,51 |
| 10 | 13,44 | 35 | 11,12 | 60 | 7,60 |
| 15 | 13,33 | 40 | 10,57 | 65 | 6,54 |
| 20 | 12,78 | 45 | 9,91 | 70 | 5,32 |

This shews the great Advantage of putting Money into the present *Fund* lately granted to Their Majesties, giving 14 *per Cent. per Annum*, or at the Rate of 7 Years Purchase for a Life; when young Lives, at the usual Rate of Interest, are worth above 13 Years Purchase. It shews likewise the Advantage of young Lives over those in Years; a Life of Ten Years being almost worth 13½ Years Purchase, whereas one of 36 is worth but 11.

*Use* V. Two Lives are likewise valuable by the same Rule; for the number of Chances of each single Life, found in the Table, being multiplied together, become the Chances of the Two Lives. And after any certain



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Term of Years, the Product of the two remaining Sums is the Chances that both the Perſons are living. The Product of the two Differences, being the numbers of the Dead of both Ages, are the Chances that both the Perſons are dead. And the two Products of the remaining Sums of the one Age multiplied by thoſe dead of the other, ſhew the Chances that there are, that each Party ſurvives the other: Whence is derived the Rule to eſtimate the Value of the Remainder of one Life after another. Now as the Product of the Two Numbers in the Table for the Two Ages propoſed, is to the difference between that Product, and the Product of the two numbers of Perſons deceaſed in any ſpace of time; ſo is the Value of a Sum of Money to be paid after ſo much time, to the Value thereof under the Contingency of Mortality. And as the aforeſaid Product of the two Numbers anſwering to the Ages propoſed, to the Product of the Deceaſed of one Age multiplied by thoſe remaining alive of the other; ſo the Value of a Sum of Money to be paid after any time propoſed, to the Value of the Chances, that the one Party has that he ſurvives the other, whoſe number of Deceaſed you made uſe of, in the ſecond Term of the Proportion. This perhaps may be better underſtood, by putting $N$ for the number of the younger Age, and $n$ for that of the Elder; $Y$, $y$ the Deceaſed of both Ages reſpectively, and $R$, $r$ for the Remainders; and $R + Y = N$ and $r + y = n$. Then ſhall $Nn$ be the whole Number of Chances; $Nn - Yy$ be the Chances that one of the two Perſons is living,

living, $Y\ y$ the Chances that they are both dead; $R\ y$ the Chances that the elder Person is dead and the younger living; and $r\ Y$ the Chances, that the elder is living and the younger dead. Thus two Persons of 18 and 35 are proposed, and after 8 Years these Chances are required. The Numbers for 18 and 35, are 610 and 490; and there are 50 of the First Age dead in 8 Years, and 73 of the Elder Age. There are in all 610 x 490, or 298900 Chances; of these there are 50 x 73, or 3650, that they are both dead. And as 298900, to 298900 — 3650, or 295250: So is the present Value of a Sum of Money to be paid after 8 Years, to the present Value of a Sum to be paid, if either of the two live. And as 560 x 73, so are the Chances that the Elder is dead, leaving the Younger; and as 417 x 50, so are the Chances that the Younger is dead, leaving the Elder. Wherefore as 610 x 490 to 560 x 73, so is the present Value of a Sum to be paid at 8 Years end, to the Sum to be paid for the Chance of the Younger's Survivance; and as 610 x 490 to 417 x 50, so is the same present Value to the Sum to be paid for the Chance of the Elder's Survivance.

This possibly may be yet better explained by expounding these Products by Rectangular Parallelograms, as in *Fig.* 7. wherein *A B* or *C D* represents the number of Persons of the younger Age, and *D E*, *B H* those remaining alive after a certain Term of Years; whence *C E* will answer the number of those dead in that time: So *A C*, *B D* may represent the number of the elder Age; *A F*, *B I* the Survi-

vors after the same Term; and *CF*, *DI*, those of that Age that are dead at that time. Then shall the whole Parallelogram *ABCD* be *Nn*, or the Product of the two Numbers of Persons, representing such a number of Persons of the two Ages given; and by what was said before, after the Term proposed, the Rectangle *HD* shall be as the number of Persons of the younger Age that survive, and the Rectangle *AE* as the number of those that die. So likewise the Rectangles *AI*, *FD* shall be as the Numbers, living and dead, of the other Age. Hence the Rectangle *HI* shall be as an equal number of both Ages surviving. The Rectangle *FE* being the Product of the Deceased, or *Yy*, an equal number of both dead. The Rectangle *GD* or *Ry*, a number living of the younger Age, and dead of the elder: And the Rectangle *AG* or *rY* a number living of the elder Age, but dead of the younger. This being understood, it is obvious, that as the whole Rectangle *AD* or *Nn* is to the *Gnomon FABDEG* or *Nn—Yy*, so is the whole number of Persons or Chances, to the number of Chances that one of the two Persons is living: And as *AD* or *Nn* is to *FE* or *Yy*, so are all the Chances, to the Chances that both are dead; whereby may be computed the Value of the Reversion after both Lives. And as *AD* to *GD* or *Ry*, so the whole number of Chances, to the Chances that the younger is living, and the other dead; whereby may be cast up what Value ought to be paid for the Reversion of one Life after another, as in the Case of providing for Clergy-mens Widows, and others, by such

Reversions.

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Reversions. And as $AD$ to $AG$, or $r$ $Y$, so are all the Chances, to those that the elder survives the younger. I have been the more particular, and perhaps tedious, in this Matter, because it is the Key to the Case of Three Lives, which of it self would not have been so easie to comprehend.

VII. If Three Lives are proposed, to find the Value of an Annuity during the continuance of any of those three Lives; the Rule is, *As the Product of the continual Multiplication of the Three Numbers, in the Table, answering to the Ages proposed, is to the difference of that Product, and of the Product of the Three Numbers of the Deceased of those Ages, in any given Term of Years: So is the present Value of a Sum of Money, to be paid certainly after so many Years, to the present Value of the same Sum to be paid, provided one of those Three Persons be living at the Expiration of that Term.* Which Proportion being yearly repeated, the Sum of all those present Values will be the Value of an Annuity granted for three such Lives. But to explain this, together with all the Cases of Survivance in Three Lives: Let $N$ be the Number in the Table for the younger Age, $n$ for the second, and $\nu$ for the elder Age; let $Y$ be those dead of the younger Age in the Term proposed, $y$ those dead of the second Age, and $\upsilon$ those of the elder Age; and let $R$ be the Remainder of the younger Age, $r$ that of the middle Age, and $\varrho$ the Remainder of the elder Age. Then shall $R + Y$ be equal to $N$, $r + y$ to $n$, and $\varrho + \upsilon$ to $\nu$, and the continual Product of the three Numbers $N n \nu$ shall be equal to the continual Product of

$R+\Upsilon \times r+y \times \varrho+v$, which being the whole Number of Chances for three Lives, is compounded of the eight Products following. (1) $R\,r\,\varrho$, which is the Number of Chances that all three of the Persons are living. (2) $r\,\varrho\,\Upsilon$, which is the Number of Chances that the two elder Persons are living, and the younger dead. (3) $R\,\varrho\,y$ the Number of Chances that the middle Age is dead, and the younger and elder living. (4) $R\,r\,v$ being the Chances that the two younger are living, and the elder dead. (5) $\varrho\,\Upsilon\,y$ the Chances that the two younger are dead, and the elder living, (6) $r\,\Upsilon\,v$ the Chances that the younger and elder are dead, and the middle Age living. (7) $R\,y\,v$, which are the Chances that the younger is living, and the two other dead. And Lastly and Eighthly, $\Upsilon\,y\,v$, which are the Chances that all three are dead. Which latter subtracted from the whole Number of Chances $N\,n\,\nu$, leaves $N\,n\,\nu - \Upsilon\,y\,v$ the Sum of all the other seven Products; in all of which one or more of the three Persons are surviving.

To make this yet more evident, I have added *Fig.* 8. wherein these eight several Products are at one view exhibited. Let the rectangled Parallelepipedon $ABCDEFGH$ be constituted of the sides $AB, GH$, &c. proportional to $N$ the Number of the younger Age; $AC, BD$, &c. proportional to $n$; and $AG, CE$, &c. proportional to the Number of the elder, or $\nu$. And the whole Parallelepipedon shall be as the Product $N\,n\,\nu$, or our whole Number of Chances. Let $BP$ be as $R$, and $AP$ as $\Upsilon$; let $CL$ be as $r$, and $Lk$ as

as $y$; and $GN$ as $\varrho$, and $NA$ as $v$; and let the Plain $PRen$ be made parallel to the Plain $ACGE$; the Plain $NVbY$ parallel to $ABCD$; and the Plain $LXTQ$ parallel to the Plain $ABGH$. And our first Product $Rr\varrho$ shall be as the Solid $STWIFZeb$. The Second, or $r\varrho Y$ will be as the Solid $EYZeQSMI$. The Third, $R\varrho y$, as the Solid $RHOVWIST$. And the Fourth, $Rrv$, as the Solid $ZabDWXIK$. Fifthly, $\varrho Yy$, as the Solid $GQRSIMNO$. Sixthly, $rYv$, as $IKLMGYZA$. Seventhly, $Ryv$, as the Solid $IKPOBXVW$. And Lastly, $AIKLMNOP$ will be as the Product of the 3 Numbers of Persons dead, or $Yyv$. I shall not apply this in all the Cases thereof for brevity-sake; only to shew in one how all the rest may be performed, let it be demanded what is the Value of the Reversion of the younger Life after the two elder proposed. The Proportion is as the whole Number of Chances, or $Nnr$ to the Product $Ryv$; so is the certain present Value of the Sum payable after any Term proposed, to the Value due to such Chances as the younger Person has to bury both the elder, by the Term proposed; which therefore he is to pay for. Here it is to be noted, that the first Term of all these Proportions is the same throughout, *viz.* $Nnr$. The second changing yearly according to the Decrease of $R, r, \varrho$, and Increase of $Y, y, v$. And the third are successively the present Values of Money payable after one, two, three, &c. years, according to the Rate of Interest agreed on. These Numbers, which are in all Cases of Annuities of necessary Use, I have put into



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the following Table, they being the Decimal Values of one Pound payable after the Number of Years in the Margent, at the Rate of *6 per Cent.*

| Years. | Pres. Value of 1 *l.* | Years. | Pres. Value of 1 *l.* | Years. | Pres. Value of 1 *l.* |
|---|---|---|---|---|---|
| 1 | 0,9434 | 19 | 0,3305 | 37 | 0,1158 |
| 2 | 0,8900 | 20 | 0,3118 | 38 | 0,1092 |
| 3 | 0,8396 | 21 | 0,2941 | 39 | 0,1031 |
| 4 | 0,7921 | 22 | 0,2775 | 40 | 0,0972 |
| 5 | 0,7473 | 23 | 0,2618 | 45 | 0,0726 |
| 6 | 0,7050 | 24 | 0,2470 | 50 | 0,0543 |
| 7 | 0,6650 | 25 | 0,2330 | 55 | 0,0406 |
| 8 | 0,6274 | 26 | 0,2198 | 60 | 0,0303 |
| 9 | 0,5919 | 27 | 0,2074 | 65 | 0,0227 |
| 10 | 0,5584 | 28 | 0,1956 | 70 | 0,0169 |
| 11 | 0,5268 | 29 | 0,1845 | 75 | 0,0126 |
| 12 | 0,4970 | 30 | 0,1741 | 80 | 0,0094 |
| 13 | 0,4688 | 31 | 0,1643 | 85 | 0,0071 |
| 14 | 0,4423 | 32 | 0,1550 | 90 | 0,0053 |
| 15 | 0,4173 | 33 | 0,1462 | 95 | 0,0039 |
| 16 | 0,3936 | 34 | 0,1379 | 100 | 0,0029 |
| 17 | 0,3714 | 35 | 0,1301 | | |
| 18 | 0,3503 | 36 | 0,1227 | | |

It were needless to advertise, that the great trouble of working so many Proportions will be very much alleviated by using Logarithms; and that instead of using $Nnr - Tyv$ for the second Term of the Proportion in finding the Value of Three Lives, it may suffice to use only $Tyv$, and then deducting the fourth Term so found out of the third, the Remainder

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der shall be the present Value sought; or all these fourth Terms being added together, and deducted out of the Value of the certain Annuity for so many Years, will leave the Value of the contingent Annuity upon the Chance of Mortality of all those Three Lives. For Example; Let there be Three Lives of 10, 30, and 40 Years of Age proposed, and the Proportions will be thus;

As 661 in 531 in 445 or 156120995, or *Nn*, to 8 in 8 in 9, or 576, or *Yy*, for the first Year, so 0,9434. to 0,000003 48.

To 15 in 16 in 18, or 4320, for the second Year, so 0,8900. to 0,00002462.

To 21 in 24 in 28, or 14112 for the third Year, so 0,8896. to 0,00008128.

To 27 in 32 in 38, for the fourth Year, so 0,7921. to 0,00016650.

To 33 in 41 in 48, for the fifth Year, so 0,7473. to 0,00031071.

To 39 in 50 in 58, for the sixth Year, so 0,7050. to 0,00051951.

And so forth to the 60th Year, when we suppose the elder Life of Forty certainly to be expired; from whence 'till Seventy we must compute for the First and Second only, and from thence to Ninety, for the single youngest Life. Then the Sum Total of all these Fourth Proportionals being taken out of the Value of a certain Annuity for 90 Years, being 16, 58 Years Purchase, shall leave the just Value to be paid for an Annuity during the whole Term of the Lives of Three Persons of the Ages proposed. And note, that it

will

will not be necessary to compute for every Year singly; but that in most Cases every 4th or 5th Year may suffice, interpoling for the intermediate Years *secundum artem.*

It may be objected, that the different *Salubrity* of Places does hinder this Proposal from being *universal*; nor can it be denied. But by the Number that die, being 1174. *per Annum* in 34000, it does appear that about a 30th part die yearly, as Sir *William Petty* has computed for *London*; and the Number that die in Infancy, is a good Argument that the Air is but indifferently salubrious. So that by what I can learn, there cannot perhaps be one better Place proposed for a Standard. At least 'tis desired, that in imitation hereof the Curious in other Cities would attempt something of the same Nature, than which nothing perhaps can be more useful.

Were this *Calculus* founded on the Experience of a very great number of Years, it would be very well worth the while to think of Methods for facilitating the Computation of the Value of two, three, or more Lives; which, as proposed in my former, seems (as I am inform'd) a Work of too much Difficulty for the ordinary Arithmetician to undertake.

I have sought, if it were possible, to find a Theorem that might be more concise than the Rules there laid down, but in vain; for all that can be done to expedite it, is, by Tables of Logarithms ready computed, to exhibit the *Rationes* of $N$ to $T$ in each single Life, for every third, fourth, or fifth Year of Age, as occasion shall require; and these Logarithms being added to the Logarithms of the present

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present Value of Money payable after so many Years, will give a Series of Numbers, the Sum of which will shew the Value of the Annuity sought. However for each Number of this Series, two Logarithms for a single Life, three for two Lives, and four for three Lives, must necessarily be added together. If you think the Matter, under the Uncertainties I have mentioned, to deserve it, I shall shortly give you such a Table of Logarithms, as I speak of, and an Example or two of the use thereof: But by Vulgar Arithmetick, the Labour of these Numbers were immense; and nothing will more recommend the useful Invention of Logarithms to all Lovers of Numbers, than the advantage of Dispatch in this and such like Computations.

Besides the Uses mentioned, it may perhaps not be an unacceptable thing to infer from the same Tables, how unjustly we repine at the shortness of our Lives, and think our selves wronged if we attain not old Age; whereas it appears hereby, that the one half of those that are born are dead in Seventeen Years time, 1238 being in that time reduced to 616. So that instead of murmuring at what we call an untimely Death, we ought with Patience and Unconcern to submit to that Dissolution which is the necessary Condition of our perishable Materials, and of our nice and frail Structure and Composition: And to account it as a Blessing that we have survived, perhaps by many Years, that Period of Life, whereat the one half of the whole Race of Mankind does not arrive.



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A ſecond Obſervation I make upon the ſaid Table, is that the Growth and Increaſe of Mankind is not ſo much ſtinted by any thing in the Nature of the *Species*, as it is from the cautious difficulty moſt People make to adventure on the State of *Marriage*, from the Proſpect of the Trouble and Charge of providing for a Family. Nor are the poorer ſort of People herein to be blamed, ſince their difficulty of ſubſiſting is occaſion'd by the unequal Diſtribution of Poſſeſſions, all being neceſſarily fed from the Earth, of which yet ſo few are Maſters. So that beſides themſelves and Families, they are yet to work for thoſe who own the Ground that feeds them: And of ſuch does by very much the greater part of Mankind conſiſt; otherwiſe it is plain, that there might well be four times as many Births as we now find. For by Computation from the Table, I find that there are nearly 15000 Perſons above 16 and under 45, of which at leaſt 7000 are Women capable to bear Children. Of theſe notwithſtanding there are but 1238 born yearly, which is but little more than a ſixth part: So that about one in ſix of theſe Women do breed yearly; whereas were they all married, it would not appear ſtrange or unlikely, that four of ſix ſhould bring a Child every Year. The Political Conſequences hereof I ſhall not inſiſt on; only the Strength and Glory of a King being in the multitude of his Subjects, I ſhall only hint, that above all things, Celibacy ought to be diſcouraged, as, by extraordinary Taxing and Military Service: And thoſe who have numerous Families of Children to be counte-



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nanced and encouraged by ſuch Laws as the *Jus trium Liberorum* among the *Romans*. But eſpecially, by an effectual Care to provide for the Subſiſtence of the Poor, by finding them Employments, whereby they may earn their Bread, without being chargeable to the Publick.



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## *A Discourse concerning* Gravity, *and its Properties, wherein the Descent of* Heavy *Bodies, and the Motion of* Projects *is briefly, but fully handled: Together with the* Solution *of a* Problem *of great Use in* Gunnery. *By* E. Halley.

NATURE amidst the great Variety of *Problems*, wherewith She exercises the Wits of Philosophical Men, scarce affords any one wherein the Effect is more visible, and the Cause more concealed, than in those of the *Phænomena* of *Gravity*. Before we can go alone, we must learn to defend our selves from the violence of its Impulse, by not trusting the *Center* of *Gravity* of our Bodies beyond our reach; and yet the acutest Philosophers, and the subtilest Enquirers into the Original of this Motion, have been so far from satisfying their Readers, that they themselves seem little to have understood the Consequences of their own *Hypotheses*.

*Des Cartes* his Notion, I must needs confess to be to me incomprehensible, while he will have the Particles of his *Celestial Matter*, by being reflected on the Surface of the *Earth*, and so ascending therefrom, to drive down into their Places those *Terrestrial Bodies* they find

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find above them: This is as near as I can gather, the Scope of the 20, 21, 22, and 23 *Sections* of the last Book of his *Principia Philosophiæ*; yet neither he, nor any of his Followers, can shew how a Body suspended in *Libero Æthere*, shall be carried downwards by a continual Impulse tending upwards, and acting upon all its Parts equally: And besides the Obscurity wherewith he expresses himself particularly, *Sect.* 23. does sufficiently argue according to his own Rules, the confused *Idea* he had of the thing he wrote.

Others, and among them Dr. *Vossius*, assert the Cause of the *Descent* of *heavy Bodies*, to be the *Diurnal Rotation* of the *Earth* upon its *Axis*, without considering, that according to the Doctrine of Motion fortified with Demonstration, all Bodies moved *in Circulo*, would recede from the Center of their Motion; whereby the contrary to *Gravity* would follow, and all loose Bodies would be cast into the Air in a *Tangent* to the *Parallel* of *Latitude*, without the intervention of some other Principle to keep them fast, such as is that of *Gravity*. Besides, the Effect of this Principle is throughout the whole Surface of the Globe found nearly equal; and certain Experiments have proved it rather less near the *Æquinoctial*, than towards the *Poles*; which could not be by any means, if the *Diurnal Rotation* of the *Earth* upon its *Axis* were the Cause of *Gravity*; for where the Motion was swiftest, the Effect would be most considerable.

Others assign the Pressure of the *Atmosphere*, to be the Cause of this Tendency towards the Center of the Earth; but unhappily they have mistaken

mistaken the Cause for the Effect; it being from undoubted Principles plain, that the *Atmosphere* has no other Pressure but what it derives from its *Gravity*; and that the Weight of the upper Parts of the *Air*, pressing on the lower Parts thereof, do so far bend the Springs of that *Elastick* Body, as to give it a Force equal to the Weight that compress'd it, having of it self no force at all: And supposing it had, it will be very hard to explain the *Modus*, how that Pressure should occasion the Descent of a Body circumscribed by it, and pressed equally above and below, without some other Force to draw, or thrust it downwards. But to demonstrate the contrary of this Opinion, an *Experiment* was long since shewn before the *Royal Society*, whereby it appeared, that the *Atmosphere* was so far from being the Cause of *Gravity*, that the Effects thereof were much more vigorous, where the Pressure of the *Atmosphere* was taken off; for a long *Glass-Receiver* having a light Down-feather included, being evacuated of Air, the Feather, which in the Air would hardly sink, did *in vacuo* descend with nearly the same *Velocity*, as if it had been a Stone.

Some think to illustrate this Descent of Heavy Bodies, by comparing it with the Vertue of the *Loadstone*; but setting aside the difference there is in the manner of their Attractions, the *Loadstone* drawing only in and about its Poles, and the Earth near equally in all Parts of its Surface, this Comparison avails no more than to explain *ignotum per æque ignotum*.

Others

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Others assign a certain *Sympathetical Attraction* between the Earth and its Parts, whereby they have, as it were, a desire to be united, to be the Cause we enquire after: But this is so far from explaining the *Modus*, that it is little more, than to tell us in other Terms, that Heavy Bodies descend, because they descend.

This, I say, not that I can pretend to substitute any Solution of this Important Philosophical Problem, that shall more happily explicate the Appearances of Gravity; only it may be serviceable to those with whom the Credit of great Authors sways much, and who too readily assent *in Verba Magistri*, to let them see that their Books are not always infallible: Besides, the detection of Errors is the first and surest Step towards the discovery of Truth.

Tho' the efficient Cause of *Gravity* be so obscure, yet the final Cause thereof is clear enough; for it is by this single *Principle*, that the *Earth* and all the *Celestial Bodies* are kept from *Dissolution*; the least of their *Particles* not being suffer'd to recede far from their *Surfaces*, without being immediately brought down again by virtue of this *Natural Tendency*; which, for their Preservation, the Infinite Wisdom of their *Creator* has ordained to be towards each of their *Centers*; nor can the *Globes* of the *Sun* and *Planets* otherwise be destroy'd, but by taking from them this Power of keeping their Parts united.

The Affections or Properties of *Gravity*, and its manner of acting upon *Bodies falling*, have been in a great measure discovered, and most

of them made out by *Mathematical Demonstration* in this our *Century*, by the accurate diligence of *Galilæus*, *Torricellius*, *Hugenius*, and others, and now lately by our worthy Country-man, Mr. *Isaac Newton*, which Properties it may be very material here to enumerate, that they may serve for a Foundation to all those that shall be willing to spend their Thoughts in search of the true Cause of this *Descent* of *Bodies*.

The first Property is, That by this Principle of *Gravitation*, all Bodies do descend towards a Point, which either is, or else is very near to the Center of Magnitude of the Earth and Sea, about which the Sea forms it self exactly into a *Spherical Surface*, and the *Prominences* of the Land, considering the Bulk of the whole, differ but insensibly therefrom.

*Secondly*, That this Point or Center of *Gravitation*, is fix'd within the *Earth*, or at least has been so, ever since we have any *Authentick History*: For a Consequence of its Change, tho' never so little, would be the over-flowing of the low Lands on that side of the *Globe* towards which it approached, and the leaving new Islands bare on the opposite side, from which it receded; but for this Two thousand Years it appears, that the low Islands of the *Mediterranean Sea* (near to which the ancient Writers lived) have continued much at the same height above the Water, as they now are found; and no *Inundations* or *Recesses* of the *Sea* arguing any such Change, are recorded



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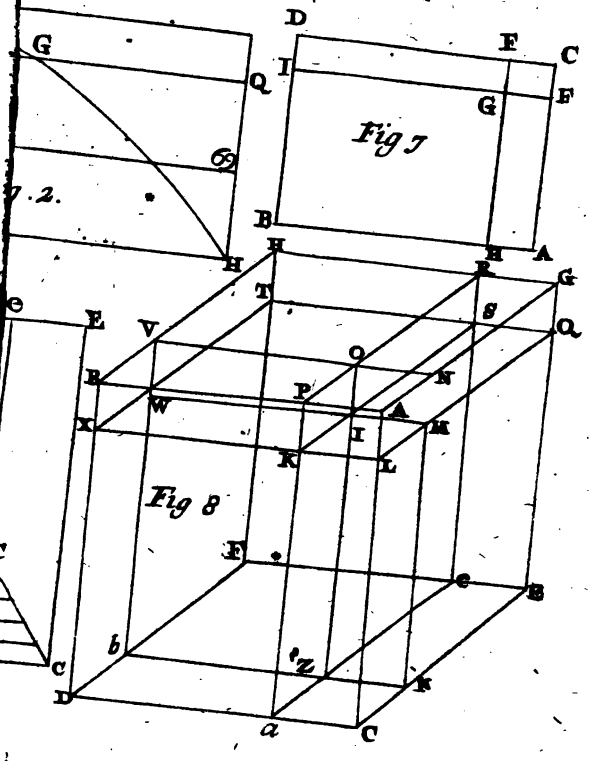
corded in History; excepting the *Universal Deluge*, which can no better way be accounted for, than by supposing this Center of *Gravitation* removed for a time, towards the middle of the then inhabited Parts of the World; and a change of its Place, but the two thousandth Part of the *Radius* of this *Globe*, were sufficient to bury the Tops of the highest Hills under Water.

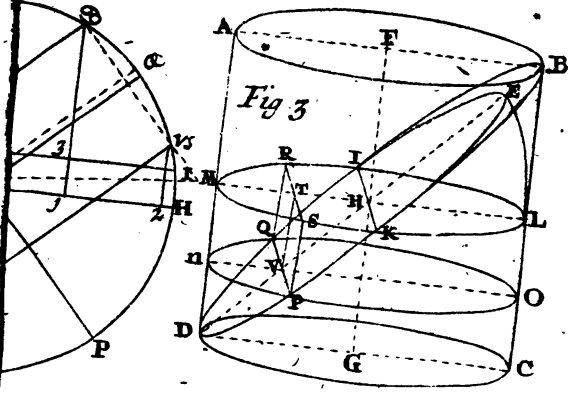
*Thirdly*, That in all Parts of the *Surface* of the *Earth*, or rather in all Points equidistant from its *Center*, the Force of *Gravity* is nearly equal; so that the length of the *Pendulum* vibrating *Seconds of Time*, is found in all Parts of the World to be very near the same. 'Tis true at S. *Helena*, in the *Latitude* of 16 Degrees *South*, I found that the *Pendulum* of my Clock, which vibrated *Seconds*, needed to be made shorter than it had been in *England*, by a very sensible Space (but which at that time I neglected to observe accurately) before it would keep time; and since the like Observations have been made by the *French Observers* near the *Æquinoctial*: Yet I dare not affirm, that in mine it proceeded from any other Cause, than the great Heighth of my Place of Observation above the *Surface* of the *Sea*, whereby the *Gravity* being diminished, the length of the *Pendulum* vibrating *Seconds*, is proportionably shortned.

*Fourthly*, That *Gravity* does equally affect all *Bodies*, without regard either to their *Matter*, *Bulk*, or *Figure*; so that the Impediment of the *Medium* being removed, the most compact and most loose, the greatest and smallest *Bodies* would descend the same *Spaces* in equal

Times; the Truth thereof will appear from the Experiment I before cited. In these two last Particulars, is shewn the great difference between *Gravity* and *Magnetism*, the one affecting only *Iron*, and that towards its *Poles*, the other all *Bodies* alike in every part. As a *Corollary*, from hence it will follow, that there is no such thing as *positive Levity*, those things that appear light, being only comparatively so; and whereas several things rise and swim in *Fluids*, 'tis because, Bulk for Bulk, they are not so heavy as those *Fluids*; nor is there any Reason why *Cork*, for Instance, should be said to be light, because it swims on Water, any more than *Iron*, because it swims on *Mercury*.

5*ly*, That this Power increases as you descend, and decreases as you ascend from the Center, and that in the Proportion of the Squares of the *Distances* therefrom *reciprocally*, so as at a double Distance to have but a quarter of the Force; this Property is the Principle on which Mr. *Newton* has made out all the *Phænomena* of the *Celestial Motions*, so easily and naturally, that its Truth is past Dispute. Besides that, it is highly rational, that the *attractive* or *gravitating* Power should exert it self more vigorously in a small Sphere, and weaker in a greater, in proportion as it is contracted or expanded; and if so, seeing that the *Surfaces* of *Spheres* are as the *Squares* of their *Radii*, this Power, at several Distances, will be as the *Squares* of those *Distances reciprocally*; and then its whole Action upon each *Spherical Surface*, be it great or small, will be always equal. And this is evidently the Rule of *Gravitation* towards

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towards the *Centers* of the *Sun*, *Jupiter*, *Saturn* and the *Earth*, and thence is reasonably inferred, to be the general Principle observed by *Nature*, in all the rest of the *Celestial Bodies*.

These are the principal Affections of *Gravity*, from which the Rules of the *Fall* of *Bodies*, and the *Motion* of *Projects* are *Mathematically* deducible. Mr. *Isaac Newton* has shew'd how to define the Spaces of the *Descent* of a *Body*, let fall from any given heighth, down to the *Center*, supposing the *Gravitation* to increase, as in the fifth Property; but considering the smallness of heighth, to which any *Project* can be made ascend, and over how little an *Arch* of the *Globe* it can be cast by any of our *Engines*, we may well enough suppose the *Gravity* equal throughout, and the Descents of *Projects* in parallel Lines, which in Truth are towards the *Center*, the difference being so small as by no means to be discovered in *Practice*. The *Opposition* of the *Air*, 'tis true, is considerable against all light Bodies moving through it, as likewise against small ones (of which more hereafter) but in great and ponderous Shot, this Impediment is found by *Experience* but very small, and may safely be neglected.

*Propositions concerning the Descent of Heavy Bodies, and the Motion of* Projects.

*Prop.* I. The *Velocities* of *falling Bodies*, are proportionate to the Times from the beginning of their *Falls*.



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This follows, for that the Action of *Gravity* being *continual*, in every Space of Time, the falling Body receives a new Impulse, equal to what it had before, in the same Space of Time, received from the same Power: For Instance, in the first Second of Time, the falling Body has acquired a *Velocity*, which in that time would carry it to a certain Distance, suppose 32 Foot, and were there no new Force, would descend at that rate with an *equable Motion*: But in the next Second of Time, the same Power of *Gravity* continually acting thereon, superadds a new *Velocity* equal to the former; so that at the end of two Seconds, the *Velocity* is double to what it was at the end of the first, and after the same manner may it be proved to be triple, at the end of the third Second, and so on. Wherefore the *Velocities* of *falling Bodies*, are proportionate to the Times of their *Falls*, *Q. E. D.*

*Prop.* II. The *Spaces* described by the Fall of a Body, are as the *Squares* of the Times, from the beginning of the *Fall*.

*Demonstration.* Let A B (*Fig.* 9. *Tab.* 4.) represent the *Time* of the *Fall* of a *Body*, B C perpendicular to A B, the *Velocity* acquired at the end of the *Fall*, and draw the Line A C; then divide the Line A B representing the Time, into as many equal Parts as you please, as b, b, b, b, &c. and through these Points draw the lines bc, bc, bc, bc, &c. parallel to B C, 'tis manifest that the several Lines, bc, represent the several *Velocities* of the falling Body, in such Parts of the *Time* as A b is of A B, by the former Proposition. It is evident likewise, that the *Area* A B C is the Sum of

all

all the Lines bc being taken, according to the Method of *Indivisibles*, infinitely many; so that the *Area* ABC represents the Sum of all the *Velocities*, between none and BC supposed infinitely many; which Sum is as the Space descended in the Time represented by AB. And by the same Reason the *Areas* A b c, will represent the Spaces descended in the Times A b; so then the Spaces descended in the Times AB, Ab, are as the *Areas* of the *Triangles* ABC, Abc, which by the 20th of the 6 of *Euclid*, are as the *Squares* of their *Homologous Sides* AB, Ab, that is to say, of the *Times*: Wherefore the Descents of *falling Bodies*, are as the *Squares* of the Times of their *Fall*, *Q. E. D.*

*Prop.* III. The *Velocity* which a *falling Body* acquires in any Space of time, is double to that, wherewith it would have moved the Space, descended by an equable Motion, in the same *time*.

*Demonstration.* Draw the Line EC parallel to AB and AE parallel to BC, in the same *Fig.* 9. and compleat the *Parallelogram* ABCE, it is evident that the *Area* thereof may represent the Space, a *Body* moved equably with the *Velocity* BC would describe in the Time AB, and the *Triangle* ABC represents the *Space* described by the *Fall* of a *Body*, in the same Time AB, by the second Proposition. Now the *Triangle* ABC is half of the *Parallelogram* ABCE; and consequently the Space described by the *Fall*, is half what would have been described by an *equable Motion* with the *Velocity* BC, in the same Time; wherefore the *Velocity* BC at the

end of the *Fall*, is double to that *Velocity*, which in the Time AB, would have described the *Space fallen*, represented by the *Triangle* ABC, with an *equable Motion*, *Q. E. D.*

*Prop.* IV. All *Bodies* on or near the Surface of the *Earth*, in their *Fall*, descend so, as at the end of the first Second of Time, they have described 16 Feet, 1 Inch, *London Measure*, and acquired the *Velocity* of 32 Feet, 2 Inches, in a Second.

This is made out from the 25th Proposition of the second Part of that excellent Treatise of Mr. *Hugenius de Horologio Oscillatorio*; wherein he demonstrates the time of the least *Vibrations* of a *Pendulum*, to be to the Time of the *Fall* of a *Body*, from the heighth of half the length of the *Pendulum*, as the *Circumference* of a *Circle* to its *Diameter*; whence, as a *Corollary*, it follows, that as the *Square* of the *Diameter* to the *Square* of the *Circumference*, so half the length of the *Pendulum* vibrating *Seconds*, to the *Space* described by the *Fall* of a *Body* in a *Second* of *Time*: And the Length of the *Pendulum* vibrating *Seconds*, being found 39, 125, or $\frac{1}{8}$ Inches, the *Descent* in a *Second* will be found by the aforesaid *Analogy* 16 Foot and 1 Inch; and, by the third Proposition, the *Velocity* will be double thereto; and near to this it hath been found by several Experiments, which by reason of the *swiftness* of the *Fall*, cannot so exactly determine its *Quantity*, The Demonstration of *Hugenius* being the Conclusion of a long Train of *Consequences*, I shall for brevity sake omit; and refer you to his Book, where these things are more amply treated of.

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From these Four *Propositions*, all *Questions* concerning the *Perpendicular Fall of Bodies*, are easily *solved*, and either *Time*, *Height*, or *Velocity* being assigned, one may readily find the other two. From them likewise is the Doctrine of *Projects* deducible, assuming the two following *Axioms*; *viz.* That a *Body* set a moving, will move on continually in a right *Line* with an *equable Motion*, unless some other Force or Impediment intervene, whereby it is accelerated, or retarded, or deflected.

*Secondly*, That a *Body* being agitated by two *Motions* at a time, does by their *compounded Forces* pass through the same *Points*, as it would do, were the two *Motions divided* and acted *successively*. As for Instance, Suppose a *Body* moved in the Line GF, (*Fig.* 1. *Tab.* 31.) from G to R, and there stopping, by another *Impulse*, suppose it moved in a *Space* of *Time* equal to the former, from R towards K, to V, I say, the *Body* shall pass through the Point V, tho' these two *several Forces* acted both in the *same time*.

*Prop.* V. The *Motion* of all *Projects* is in the *Curve* of a *Parabola*. Let the *Line* GRB (in *Fig.* 1.) be the *Line* in which the *Project* is directed, and in which by the first *Axiom* it would move equal *Spaces* in equal *Times*, were it not deflected downwards by the Force of *Gravity*. Let GB be the *Horizontal Line*, and GC a *Perpendicular* thereto. Then the *Line* GRF being divided into equal Parts, answering to equal *Spaces* of *Time*, let the *Descents* of the *Project* be laid down in *Lines* parallel to GC, proportioned as the *Squares* of the *Lines* GS, GR, GL, GF, or as the *Squares* of

of the *Times*, from S to T, from R to V, from L to X, and from F to B, and draw the *Lines* TH, VD, XY, BC parallel to GF; I say the Points T, V, X, B, are Points in the *Curve* described by the *Project*, and that that *Curve* is a *Parabola*. By the second *Axiom*, they are Points in the *Curve*; and the Parts of the *Descent* GH, GD, GY, GC, = to ST, RV, LX, FB, being as the *Squares* of the *Times* (by the *second Prop.*) that is, as the *Squares* of the *Ordinates*, HT, DU, YX, BC, equal to GS, GR, GL, GF, the *Spaces* measured in those Times; and there being no other *Curve* but the *Parabola*, whose Parts of the *Diameter* are as the *Squares* of the *Ordinates*, it follows that the *Curve* described by a *Project*, can be no other than a *Parabola*: And saying, as RU the *Descent* in any *time*, to GR or UD the *direct Motion* in the same *time*, so is UD to a *third* proportional; that *third* will be the *Line* called by all Writers of *Conicks*, the *Parameter* of the *Parabola* to the *Diameter* GC, which is always the same in *Projects* cast with the same *Velocity*: And the *Velocity* being defined by the Number of *Feet* moved in a *Second* of Time, the *Parameter* will be found by dividing the *Square* of the *Velocity*, by 16 *Feet*, 1 *Inch*, the *Fall* of a *Body* in the same *Time*.

*Lemma.*

The *Sine* of the double of any *Arch*, is equal to twice the *Sine* of that *Arch* into its *Co-sine*, divided by *Radius*; and the *versed Sine* of the *double* of any *Arch* is equal to twice the *Square* of the *Sine* thereof divided by *Radius*.

Let

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Let the *Arch* BC (in *Fig.* 2. *Tab.* 5.) be double the *Arch* BF, and A the *Center*; draw the *Radii* AB, AE, AC, and the *Chord* BDC, and let fall BE perpendicular to AC, and the *Angle* BBC, will be equal to the *Angle* ABD, and the *Triangle* BCE, will be like to the *Triangle* BDA; wherefore it will be as AB to AD, so BC or twice BD, to BE; that is, as *Radius* to *Co-sine*, so twice *Sine*, to *Sine* of the double *Arch*. And as AB to BD, so twice BD or BC to EC; that is, as *Radius* to *Sine*, so twice that *Sine*, to the *Versed Sine* of the double *Arch*; which two *Analogies* resolved into *Equations*, are the *Propositions* contained in the *Lemma* to be proved.

*Prop.* VI. The *Horizontal* Distances of *Projections* made with the same *Velocity*, at several *Elevations* of the *Line* of Direction, are as the *Sines* of the doubled *Angles* of *Elevation*.

Let GB (*Fig.* 1.) the *Horizontal* Distance be $= z$, the *Sine* of the *Angle* of *Elevation*, FGB, be $= s$, its *Co-sine* $= c$, *Radius* $= r$, and the *Parameter* $= p$. It will be as $c$ to $s$; so $z$ to $\frac{sz}{c} =$ FB $=$ GC, and by reason of the *Parabola* $\frac{psz}{cc} =$ to the *Square* of CB, or GF. Now as $c$ to $r$, so is $z$ to $\frac{rz}{c} =$ GF, and its *Square* $\frac{rrzz}{cc}$ will be therefore $=$ to $\frac{psz}{c}$; which *Equation* reduced will be $\frac{psc}{rr} = z$. But by the former *Lemma* $\frac{2sc}{r}$ is equal to the *Sine* of the double

the *Angle*, whereof *s* is the *Sine*: Wherefore it will be as *Radius* to *Sine* of double the *Angle* FGB, so is half the *Parameter*, to the *Horizontal Range* or *Distance* sought; and at the several *Elevations*, the *Ranges* are as the *Sines* of the double *Angles* of *Elevation* *Q. E. D.*

*Corollary.*

Hence it follows, that half the *Parameter* is the greatest *Random*, and that that happens at the *Elevation* of 45 Degrees, the *Sine* of whose double is *Radius*. Likewise that the *Ranges* equally distant above and below 45 are equal, as are the *Sines* of all doubled *Arches*, to the *Sines* of their doubled *Complements*.

*Prop.* VII. The *Altitudes* of *Projections* made with the same *Velocity*, at several *Elevations*, are as the *versed Sines* of the doubled *Angles* of *Elevation*: As *c* is to *s* :: so is $\frac{p\,s\,c}{r\,r}$ = GB to $\frac{p\,s\,s}{r\,r}$ = BF: and UK = RU = $\frac{BF}{4}$, the *Altitude* of the *Projection* = $\frac{p\,s\,c.}{4\,r\,r}$ Now by the foregoing *Lemma* $\frac{2\,s\,s}{r}$ = to the *versed Sine* of the double *Angle*, and therefore it will be as *Radius*, to *versed Sine* of double the *Angle* FGB, so an 8th of the *Parameter* to the height of the *Projection* VK; and so these heights at several *Elevations*, are as the said *versed Sines*, *Q. E. D.*

*Corollary.*

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*Corollary.*

From hence it is plain, that the greatest *Altitude* of the perpendicular *Projection* is a 4th of *Parameter*, or half the greatest *Horizontal Range*; the *versed Sine* of 180 Degrees being $= 2r$.

*Prop.* VIII. The *Lines* G F, or Times of the Flight of a *Project* cast with the same Degree of *Velocity* at different *Elevations*, are as the *Sines* of the *Elevations*.

As $c$ is to $r$ :: so is $\frac{p \cdot s \cdot c}{rr} \cdot \frac{1}{2} =$ GB by the 6 Prop. to $\frac{p \cdot s}{r} =$ GF, that is, as *Radius* to *Sine* of *Elevation*, so the *Parameter* to the *Line* GF; so the *Lines* GF are as the *Sines* of *Elevation*, and the *Times* are proportional to those *Lines*; wherefore the *Times* are as the *Sines* of *Elevation*: *Ergo constat propositio.*

*Prop.* IX. Problem. A *Projection* being made as you please, having the Distance and Altitude, or Descent, of an Object, through which the Project passes, together with the *Angle* of *Elevation* of the *Line* of *Direction*; to find the *Parameter* and *Velocity*, that is (in *Fig.* 1.) having the *Angle* FGB, GM, and MX.

*Solution.* As *Radius* to *Secant* of FGB, so GM the *Distance* given to GL; and as *Radius* to *Tangent* of FGB, so GM to LM. Then LM — MX in *Heights*, or + MX in *Descents*; or else MX — ML, if the *Direction* be below the *Horizontal Line*, is the *Fall* in the *Time* that the direct *Impulse* given in G would have carried the Project from G to L = LX = GY; then by Reason

Reason of the *Parabola*, as LX or GY, is to GL or YX, :: so is GL to the *Parameter* sought. To find the *Velocity* of the *Impulse*: by Prop. 2, and 4, find the Time in Seconds that a Body would fall the Space LX; and by that dividing the Line GL, the *Quote* will be the *Velocity*, or Space moved in a Second sought, which is always a mean Proportional between the *Parameter*, and 16 Feet, 1 Inch.

*Prop. X.* Problem 2. Having the *Parameter*, Horizontal Distance, and Height or Descent of an *Object*, to find the Elevations of the Line of Direction necessary to hit the given *Object*; that is, having GM, MX, and the greatest *Randon* equal to half the *Parameter*; to find the *Angles* FGB.

Let the *Tangent* of the *Angle* sought be $=t$, the *Horizontal Distance* GM $=b$, the Altitude of the *Object* MX $=h$, the *Parameter* $=p$, and *Radius* $=r$, and it will be,

As $r$ to $t$, so $b$ to $\frac{tb}{r}$ $=$ ML and $\frac{tb}{r} + h$ in ascents $=$ LX, and in descents $\frac{ptb}{r} + ph =$ GL *quad.* $=$ XY *quad. ratione Parabolæ*; but $bb + \frac{ttbb}{rr} =$ GL *quad.* 47. 1. *Euclid.* Wherefore $\frac{ptb}{r} + ph = bb + \frac{ttbb}{rr}$ which Equation transposed, is $\frac{ttbb}{rr} = \frac{ptb}{r} + ph - bb$, divided by $bb$ is

$\frac{tt}{rr}$

$\frac{tt}{rr} - \frac{pt}{br} + \frac{ph}{bb} = 1$. this Equation shews the Question to have 2 Answers, and the Roots thereof are $t = \frac{p}{2b} \pm \sqrt{\frac{pp}{4bb} - \frac{ph}{bb}} \times r$ from which I derive the following Rule.

Divide half the *Parameter* by the Horizontal distance, and keep the Quote; *viz.* $\frac{p}{2b}$ or $\frac{1}{2}$ then say, as *square* of the *distance* given to the half *Parameter*, so half *Parameter* + double height descent to the *square* of a *Secant* $= \frac{pp + 4ph}{4bb}$. The *Tangent* answering to that *Secant*, will be $\sqrt{\frac{pp + 4ph}{4bb}} - 1$ or Square of Radius, so then the sum and difference of the aforefound *Quote*, and this *Tangent* will be the Roots of the *Equation*, and the *Tangents* of the *Elevations* sought.

Note here, that in *Descents*, if the *Tangent* exceed the *Quote*, as it does when $ph$ is more than $bb$, the *direction* of the lower *Elevation* will be below the *Horizon*, and if $ph = bb$, it must be directed *Horizontal*, and the *Tangent* of the upper *Elevation* will be $\frac{pr}{b}$: Note likewise, that if $4bb + 4ph$ in *ascents*, or $4bb - 4ph$ in *descents*, be equal to $pp$, there is but one *Elevation* that can hit the *Object*, and its *Tangent* is $\frac{pr}{2b}$. And if $4bb + 4ph$ in *ascents*,

or

or $4bb - 4ph$ in *descents*, do exceed $pp$, the *Object* is without the reach of a *Project* cast with that *Velocity*, and so the thing impossible.

From this *Equation* $4bb + 4ph = pp$ are determined the utmost limits of the reach of any *Project*, and the Figure assigned, wherein are all the *heights* upon each *Horizontal distance* beyond which it cannot pass; for by reduction of that *Equation*, $h$ will be found $= \frac{1}{4}p - \frac{bb}{p}$ in *heights*, and $\frac{bb}{p} - \frac{1}{4}p$ in *descents*; from whence it follows, that all the Points $h$ are in the *Curve* of the *Parabola*, whose *Focus* is the Point from whence the *Project* is cast, and whose *Latus rectum*, or *Parameter ad Axem* is $= p$. Likewise from the same *Equation* may the least *Parameter* or *Velocity* be found capable to reach the *Object* proposed; for $bb = \frac{1}{4}pp - ph$ being reduced $\frac{1}{2}p$ will be $= \sqrt{bb + hh} - h$ in ascents / $\sqrt{bb + hh} + h$ in descents, which is the *Horizontal Range* at 45 degrees, of a Project cast with the least Velocity that would just reach the *Object*, and the *Elevation* requisite will be easily had; for dividing the so found *Semi-parameter* by the *Horizontal distance* given by the *Quere* into *Radius* will be the *Tangent* of the *Elevation* sought. This Rule may be of good use to all *Bombardiers* and *Gunners*, not only that they may use no more Pouder than is necessary, to cast their *Bombs* into the place assigned, but that they may shoot with much more certainty, for that a small Error committed in the *Elevation* of the *Piece*, will produce no sensible Difference in the fall of the

Shot: For which Reasons the *French* Engineers in their late Sieges have used Mortar-pieces inclin'd constantly to the *Elevation* of 45, proportioning their Charge of Pouder according to the distance of the *Object* they intend to strike on the *Horizon*.

And this is all that need to be said concerning this *Problem* of shooting upon *Heights* and *Descents*. But if a *Geometrical* Construction thereof be required; I think I have one that is as easy as can be expected, which I deduce from the foregoing *Analytical Solution*, *viz.* $\frac{t}{r} = \frac{p}{2b} + \frac{\sqrt{\frac{1}{4}pp \pm ph - bb}}{bb}$, and 'tis this having made the right Angle GDF, (*Tab.* 5. *Fig.* 3.) make $DF = \frac{1}{2}p$, or greatest Range, and $GD = b$ the Horizontal Distance, and $DB = h$ the perpendicular heighth of the Object; to be laid upwards from D, if the Object be above the Horizon, or downwards if below it. Parallel to GD draw FA, and make it equal to GB the Hypothenusal Distance of the Object; and with the Center A and Radius $FB = \frac{1}{2}p \pm h$ sweep an Arch, which shall if the thing be possible, intersect the indeterminate Perpendicular DF in two Points K and L, to which draw the Lines, GL, GK, I say, the Angles DGK, DGL, are the Elevations requisite to strike the Object B.

*Demonstration.* The Sq. of FK or FL, is equal to $FB\,q - GB\,q$: or $\frac{1}{4}pp \pm bh^{2} - bb - bb$ or $\frac{1}{4}pp \pm ph - bb$, and therefore $\sqrt{\frac{1}{4}pp \pm ph - bb}$ is $= FK = FL$, and by Consequence $DK$, $DL = \frac{1}{2}p \pm \sqrt{\frac{1}{4}pp \pm ph - bb}$. And as DG: DK and DL :: Radius : Tangents sought,



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which coincides with our Algebraical Expression thereof.

*Prop.* XI. To determine the Force or *Velocity* of a *Project*, in every Point of the *Curve* it describes.

To do this we need no other *Præcognita*, but only the third Proposition, *viz.* That the *Velocity* of *falling Bodies*, is double to that which in the same time, would have described the Space *fallen* by an equable Motion: For the *Velocity* of a Project, is compounded of the constant equal *Velocity* of the impressed Motion, and the *Velocity* of the *Fall*, under a given *Angle*, *viz.* the Complement of the *Elevation*: For Instance, in *Fig.* 2. in the time wherein a Project would moue from G to L, it descends from L to X, and by the third *Proposition* has acquired a *Velocity*, which in that time would have carried it by an equable Motion from L to Z, or twice the Descent L X; and drawing the Line G Z, I say, the *Velocity* in the Point X, compounded of the *Velocities* G L and L Z under the Angle G L Z, is to the *Velocity* impress in the Point G, as G Z is to G L; this follows from our second *Axiome*, and by the 20 and 21 *Prop. lib.* 1. *conic. Midorgii*, X O parallel and equal to G Z shall touch the *Parabola* in the Point X. So that the *Velocities* in the several Points, are as the lengths of the *Tangents* to the *Parabola* in those Points, intercepted between any two *Diameters*: And these again are as the *Secants* of the *Angles*, which those *Tangents* continued make with the *Horizontal* Line G B. From what is here laid down, may the comparative Force of a *Shot* in any two Points of the *Curve*, be either *Geometrically* or *Arithmetically* discovered.

*Corollary*,

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*Corollary.*

From hence it follows, that the force of a Shot is always least at U, or the *Vertex* of the *Parabola*, and that at equal distances therefrom, as at T and X, G and B its force is always equal, and that the least force in U is to that in G and B, as *Radius* to the Secant of the *Angle* of *Elevation* F G B.

These *Propositions* considered, there is no question relating to *Projects*, which, by the help of them, may not easily be Solved; and tho' it be true that most of them are to be met withal, in *Galileus Torricellius* and others, who have taken them from those Authors, yet their Books being Forreign, and not easy to come by, and their *Demonstrations* long and difficult, I thought it not amiss to give the whole *Doctrine* here in *English*, with such short *Analytical* Proof of my own, as might be sufficient to evince their Truth.

The Tenth *Proposition* contains a *Problem*, untouch'd by *Torricellius*, which is of the greatest use in *Gunnery*, and for the sake of which this *Discourse* was principally intended: It was first Solved by Mr. *Anderson*, in his Book of the Genuine Use and Effects of the *Gun*, Printed in the Year 1674; but his Solution required so much Calculation, that it put me upon search, whether it might not be done more easily, and thereupon in the Year 1678 I found out the Rule I now Publish, and from it the *Geometrical* Construction: Since which time there has a large *Treatise* of this Subject Intitl'd, *L'art de jetter les Bombes*, been Pub-



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lish'd by *Monsieur Blondel*, wherein he gives the Solutions of this *Problem* by *Messieurs Buot*, *Romér* and *de la Hire*: But none of them being the same with mine, or, in my Opinion, more easy, and most of them more Operose, and besides mine finding the *Tangent*, which generally determines the *Angle* better than its *Sine*, I thought my self obliged to Print it for the use of all such, as desire to be informed in the *Mathematical* part of the Art of *Gunnery*.

Now these Rules were rigidly true, were it not, as I said before, for the Opposition of the Medium, whereby not only the direct impress Motion is continually retarded, by likewise the increase of the *Velocity* of the *Fall*, so that the spaces described thereby, are not exactly as the squares of the Times: But what this Opposition of the *Air* is, against several *Velocities*, *Bulks*, and *Weights*, is not so easy to determine. 'Tis certain that the weight of *Air* to that of *Water*, is nearly as 1 to 800, whence the weight thereof, to that of any *Project* is given; 'tis very likely, that to the same *Velocity*, and *Magnitude*, but of different matter, the *Opposition* should be *reciprocally* as the weights of the Shot; as likewise that to Shot of the same *Velocity* and Matter, but of different Sizes, it should be as the *Diameters reciprocally*: Whence generally the *Opposition* to Shot with the same *Velocity*, but of differing *Diameters*, and *Materials*, should be as their *Specifick Gravities* into their *Diameters reciprocally*; but whether the *Opposition*, to differing *Velocities* of the same Shot, be as the *Squares* of those *Velocities*,

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*ties*, or as the *Velocities* themselves, or otherwise, is yet a harder Question. However it be, 'tis certain, that in large Shot of *Mettal*, whose weight many Thousand times surpasses that of the *Air*, and whose force is very great, in proportion to the *Surface* wherewith they press thereon; this *Opposition* is scarce discernable: For by several *Experiments* made with all Care and Circumspection with a *Morterpeice*, Extraordinary well fixt to the Earth on purpose, which carried a solid Brass Shot of four Inches and a half *Diameter*, and of about fourteen Pound Weight, the *Ranges* above and below forty five *Degrees* were found nearly equal; if there were any difference, the under *Ranges* went rather the farthest, but those differences were usually less than the Errours committed in ordinary Practice, by the unequal Goodness and Dryness of the same sort of Pouder, by the Unfitness of the Shot to the Bore, and by the Looseness of the Carriage.

In a smaller Brass-Shot of about an Inch and half Diameter, cast by a Cross-Bow which ranged it, at most about four Hundred Foot, the Force being much more equal than in the Morterpiece, this difference was found more Curiously: and Constantly and most Evidently, the under Ranges out went the upper: From which Trials I conclude, that altho' in small and light Shot, the Opposition of the Air, ought and must be accounted for; yet in Shooting of great and weighty Bombs, there need be very little or no allowance made; and so these Rules may be put in practice to all



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Intents and Purposes, as if this Impediment were absolutely remov'd.

*A Proposition of general Use in the Art of Gunnery, shewing the Rule of laying a Mortar to pass, in order to strike an Object above or below the Horizon.*

It was formerly the Opinion of those concerned in Artillery, that there was a certain requisite of Pouder for each Gun, and that in Mortars, where the distance was to be varied, it must be done by giving a greater or lesser Elevation to the Peice. But now our later Experience has taught us that the same thing may be more certainly and readily performed by increasing and diminishing the quantity of Pouder, whether regard be had to the Execution to be done, or to the Charge of doing it. For when Bombs are discharged with great Elevations of the Mortar, they fall too Perpendicular, and bury themselves too deep in the Ground, to do all that damage they might, if they came more Oblique, and broke upon or near the Surface of the Earth; which is a thing acknowledged by the Besieged in all Towns, who unpave their Streets, to let the Bombs bury themselves, and thereby stifle the force of their Splinters. A Second Convenience is, that at the extream Elevation, the Gunner is not obliged to be so curious in the direction of his Piece, but it will suffice to be within a Degree or two of the Truth; whereas in the other method of Shooting he ought to be very curious. But a Third, and no less considerable Advantage is, in the saving the



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Prince's Pouder, which in so great and so numerous Discharges, as we have lately seen, must needs amount to a considerable Value. And for Sea-Mortars; it is scarce practicable otherwise to use them, where the agitation of the Sea continually changes the Direction of the Mortar, and would render the Shot very uncertain, were it not that they are placed about 45 Degrees Elevation, where several Degrees above or under, makes very little difference in the Effect.

In the precedent Discourse, I considered all the Propositions relating to the Motion of Projectiles, and gave a Solution to this Problem; *viz. To hit an Object above or below the Horizontal Line with the greatest Certainty and least Force.* That is, that the Horizontal distance of the Object being put $= b$, and the Perpendicular Heighth $= h$, the Charge requisite to strike the Object with the greatest Advantage, was that which with an Elevation of 45° would cast the Shot on the Horizontal Line, to the distance of $\sqrt{+bb\,bb}+b$ when the Object was above the Horizon; or if it were below it, the Charge must be lesser, so as to reach on the Horizon, at 45° Elevation, no greater a Distance than $\sqrt{+bb+bb}-b$; that is, in the one Case, the Sum of the Hypothenusal Distance of the Object from the Gun, and the Perpendicular Heighth thereof above the Gun; and in the other Case, when the Object is below the Horizon, the difference of the same *per* 47. 1 *Eucl.* And I then shew'd how to find the Elevation proper for the Gun so charged, *viz.* As the

Horizontal Distance of the Object, to the Sum or Difference of the Hypothenusal Distance and Perpendicular Heighth :: So Radius to the Tangent of the Elevation sought. But I was not at that time aware that the aforesaid Elevation did constantly bisect the Angle between the Perpendicular and the Object, as is demonstrated from the Difference and Sum of the *Tangent* and *Secant* of any Arch being always equal to the *Tangent* and and *Cotangent* of the half Complement thereof to a Quadrant. Having discovered this, I think nothing can be more compendious, or bids fairer to compleat the Art of Gunnery, it being as easie to shoot with a Mortar at any Object on demand, as if it were on the Level; neither is there need of any Computation, but only simply laying the Gun to pass in the middle Line between the Zenith and the Object, and giving it its due Charge. Nor is there any great need of Instruments for this purpose: For if the Muzzle of the Mortar be turned truly Square to the Bore of the Piece, as it usually is or ought to be, a Piece of Looking-glass Plate applied parallel to the Muzzle, will by its Reflection give the true Position of the Piece, the Bombardeer having no more to do, but to look perpendicularly down on the Looking-glass, along a small Thread with a Plumbet, and to raise or depress the Elevation of the Piece, till the Object appear reflected on the same Point of the *Speculum*, on which the Plumbet falls; for the Angle of Incidence and Reflection being equal, in this Case a Line at Right Angles to the *Speculum*, as is the *Axis* of the Chase of the

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the Piece, will bisect the Angle between the Perpendicular and the Object, according as our Proposition requires. So that it only remains by good and valid Experiments to be assured of the Force of Gunpouder, how to make and conserve it equal, and to know the Effect thereof in each Piece; that is, how far differing Charges will cast the same Shot out of it; which may most conveniently be engraven on the outside thereof, as a standing Direction to all Gunners, who shall from thence forward have occasion to use that Piece. And were this Matter well ascertained, it might be worth the while to make all Mortars of the like Diameter as near as may be, alike in length of Chase, Weight, Chamber, and all other Circumstances.

This Discovery that the utmost Range on an inclined Plane, is, when the *Axis* of the Piece makes equal Angles with the Perpendicular and the Object, compared with what I have demonstrated of the same Problem in the aforesaid Discourse does lead to and discover two very ready Theorems; the one, to find the greatest Horizontal Range at 45° Elevation, by any Shot made upon any inclined Plane, with any Elevation of the Piece whatsoever: And the other to find the Elevations proper to strike a given Object, with any Force greater than what suffices to reach it with the aforesaid middle Elevation. Both which being performed by one single Proportion, may be very serviceable to such as are concerned in the Practice of Gunnery, but are unwilling to trouble themselves with tedious

tedious and difficult Rules. The two Propositions are these.

## *PROP.* I.

A Shot being made on an inclined Plane, having the Horizontal Distance of the Object it strikes, with the Elevation of the Piece, and the Angle at the Gun between the Object and the Perpendicular; to find the greatest Horizontal Range of that Piece, laden with the same Charge; that is, half the *Latus rectum* of all the *Parabola* made with the same *Impetus*.

### *RULE.*

Take half the Distance of the Object from the *Nadir*, and take the Difference of the given Elevation from that half; the Versed Sine of that Difference subtract from the Versed Sine of the Distance of the Object from the *Zenith*: Then shall the Difference of those Versed Sines be to the Sine of the Distance of the Object from the *Zenith*, as the Horizontal Distance of the Object struck, to the greatest Horizontal Range at 45°.

## *PROP.* II.

Having the greatest Horizontal Range of a Gun, the Horizontal Distance and Angle of Inclination of an Object to the Perpendicular, to find the two Elevations necessary to strike that Object.

### *RULE.*

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## *RULE.*

Halve the Distance of the Object from the *Nadir*; this half is always equal to the half Sum of the two Elevations we seek. Then say, *As the greatest Horizontal Range is to the Horizontal Distance of the Object: So is the Sine of the Angle of Inclination or Distance of the Object from the Perpendicular, to a fourth Proportional; which fourth being subtracted from the Versed Sine of the Distance of the Object from the* Zenith, *leaves the Versed Sine of half the Difference of the Elevations sought; which Elevations are therefore had by adding and subtracting that half Difference to and from the aforesaid half Sum.*

I shall not need to speak of the Facility of these Solutions, I shall only observe that they are both General, without Exception or Caution, and derived from the Knowledge that these two Elevations are equidistant above and below the Line, bisecting the Angle between the Object and the *Zenith*.



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## *A Diſcourſe concerning the Meaſure of the Airs reſiſtance to Bodies moved in it. By the Learned* John Wallis, *S. T. D. and R. S. Soc.*

1. THAT the Air (and the like of any other *Medium*) doth conſiderably give reſiſtance to Bodies moved in it; (and doth thereby abate their Celerity and Force:) is generally admitted. And Experience doth atteſt it: For otherwiſe, a Cannot-Bullet projected Horizontally, ſhould (ſuppoſing the Celerity and Force undiminiſhed) ſtrike as hard againſt a perpendicular Wall, erected at a great diſtance, as near at hand; which we find it doth not.

2. But at what Rate, or in what Proportion, ſuch reſiſtance is; and (conſequently, at what Rate the Celerity and Force is continually diminiſhed) ſeems not to have been ſo well examined. Whence it is, that the Motion of a Project (ſecluding this Conſideration) is commonly reputed to deſcribe a Parabolick Line; as ariſing from an uniform or equal Celerity in the Line of Projection, and a Celerity uniformly accelerated in the Line of Deſcent; which two ſo compounded, do create a Parabola.

3. In

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3. In order to the Computation hereof, I first premise this *Lemma*, (as the most rational that doth occur for my first footing,) That (supposing other things equal) the resistance is proportional to the Celerity. For in a double Celerity, there is to be removed (in the same time) twice as much Air, (which is a double Impediment) in a treble, thrice as much; and so in other Proportions.

4. Suppose we then the Force impressed (and consequently the Celerity, if there were no resistance) as 1; the resistance as $r$. (which must be less than the Force, or else the Force would not prevail over the Impediment, to create a Motion.) And therefore the effective Force at a first Moment, is to be reputed as $1-r$: That is, so much as the Force impressed, is more than the Impediment or Resistance.

5. Be it as $1-r$ to 1; so one to $m$. (which $m$ is therefore greater than 1.)

6. And therefore the effective Force (and consequently the Celerity) as to a first Moment, is to be $\frac{1}{m}$ of what it would be, had there been no resistance.

7. This $m$ is also the remaining Force after such first Moment; and this remaining Force is (for the same Reason) to be proportionally abated as to a second Moment; that is, we are to take $\frac{1}{m}$ thereof, that is $\frac{1}{mm}$ of the impressed Force. And for a third Moment (at equal distance of time) $mmm$; for a fourth $\frac{1}{m^4}$; and so onward infinitely.

8. Because

8. Because the length dispatched (in equal times) is proportional to the Celerities; the Lines of Motion (answering to those equal Times) are to be as $m, m^{\frac{1}{2}}, m^{\frac{1}{3}}, m^{\frac{1}{4}}$, &c. of what they would have been, in the same Times, had there been no resistance.

9. This therefore is a Geometrical Progression; and (because of $m$ greater than 1) continually decreasing.

10. This decreasing Progression infinitely continued (determining in the same Point of Rest, where the Motion is supposed to expire) is yet of a finite Magnitude; and equal to $m^{\frac{1}{1}}-1$ of what it would have been in so much Time, if there had been no resistance. As is demonstrated in my Algebra, *Chap.* 95. *Prop.* 8. For (as I have elsewhere demonstrated) the Sum or Aggregate of a Geometrical Progression is $\frac{VR-A}{R-1}$ (supposing $V$ the greatest Term, $A$ the least, and $R$ the common Multiplier.) That is $\frac{VR}{R-1} - \frac{A}{R-1}$. Now in the present Case, (supposing the Progression infinitely continued) the least Term $A$, becomes infinitely small, or $= 0$. And consequently $\frac{A}{R-1}$ doth also vanish, and thereby the Aggregate becomes $= \frac{V}{R-1}$. That is

(as

(as will appear by dividing $VR$ by $R-1$;) $V + \frac{V}{R} + \frac{V}{RR} + \frac{V}{R^3} + \&c. = \frac{VR}{R-1}$; (supposing the Progression to begin at $V=1$.) That is (dividing all by $R$, that so the Progression may begin at $\frac{V}{R} = \frac{1}{m}$:) $\frac{V}{R-1} = \frac{V}{R} + \frac{V}{RR} + \frac{V}{R^3} + \&c.$ That is, in our present Case (because of $V=1$, & $R=m$:) $\frac{1}{m} + \frac{1}{mm} + \frac{1}{m^3}$ &c. $= \frac{1}{m-1}$. That is, (putting $n=m-1$:) $\frac{1}{n}$ of what it would have been if there had been no resistance.

$R-1)VR(V+\frac{V}{R}\ \frac{V}{RR}\ \&c.$
$VR-V$
$+V$
$+V-\frac{V}{R}$
$+\frac{V}{R}$
$+\frac{V}{R}-\frac{V}{RR}$
$+\frac{V}{RR}$
&c.

11. This infinite Progression is fitly expressed by an Ordinate in the exterior Hyperbola, parallel to one of the Asymptotes; and the several Members of that, by the several Members of this, cut in continual Proportion. As is there demonstrated at *Prop.* 15. For let $SH$, (*vid.* Fig. 4. Tab. 5.) be an Hyperbola between the Asymptotes $AB$, $AF$: And let the Ordinate $DH$ (in the exterior Hyperbola, parallel to $AF$,) represent the impressed Force undiminished; or the Line to be described in such time, by a Celerity answerable to such undiminished Force. And let $BS$ (a like Ordinate) be $\frac{1}{m}$ thereof; which therefore, being less than $DH$ (as being equal to a Part of it) will be farther than it from $AF$. In $AB$ (which I put $=1$) let $Bd$ be such a Part thereof, as is $BS$ of $DH$.

Now

Now because (as is well known) all the inscribed Parellelograms, in the exterior Hyperbola, $AS$, $AH$, &c. are equal; and therefore their sides reciprocal: Therefore as $Ad = 1 - \frac{1}{m}$ (supposing $Bd$ to be taken, from $B$ toward $A$,) to $AB = 1$, (or as $m - 1$ to $m$:) so is $BS = \frac{1}{m} DH$, to $db$, which is therefore equal to $\frac{1}{m-1}$ of $DH$; that is (as will appear by dividing 1, by $m - 1$,) to $\frac{1}{m} + \frac{1}{mm} + \frac{1}{m^3}$ &c. of $DH$.

$$m-1)\ 1\ \left(\frac{1}{m}+\frac{1}{mm}+\frac{1}{m^3}+\text{\&c.}\right.$$
$$1-\frac{1}{m}$$
$$+\frac{1}{m}$$
$$+\frac{1}{m}-\frac{1}{mm}$$
$$+\frac{1}{mm}$$
$$+\frac{1}{mm}+\frac{1}{mmm}$$
$$+\frac{1}{mmm}$$
$$\text{\&c.}$$

Or if $Bd$ be taken beyond $B$; then as $Ad = 1 + \frac{1}{m}$, to $AB = 1$, or as $m + 1$ to $m$, so is $\frac{1}{m} DH$ to $db$, which is therefore equal to $\frac{1}{m+1} DH$; that is (as will appear by like dividing of 1 by $m + 1$;) = to $\frac{1}{m} - \frac{1}{mm} + \frac{1}{m^3}$ — &c. of $DH$.

12. Let such ordinate $db$, or (equal to it in the Asymptote) $AF$, be so divided in $L$, $M$, $N$, &c. (by Perpendiculars cutting the Hyperbola in $l$, $m$, $n$, &c.) as that $FL$, $LM$ $MN$

$MN$ be as $m$, $\frac{1}{m}m$, $\frac{1}{m^2}$ &c. That is, so continually decreasing, as that each Antecedent be to its Consequent, as 1 to $\frac{1}{m}$, or as $m$ to 1. See *Fig.* 5. *Tab.* 5.

13. This is done by taking $AF$, $AL$, $AN$, &c. in such proportion. For, of continual Proportionals, the differences are also continually proportional, and in the same proportion. For let $A, B, C, D$, &c. be such Proportionals, and their Differences $a, b, c$, &c. That is $A - B = a$, $B - C = b$, $C - D = c$, &c.

Then, because A, B, C, D, &c. are in continual proport.
That is A. B :: B. C :: C. D :: &c.
And dividing A − B. B :: B − C. C :: C − D. D :: &c.
That is *a*. B :: *b*. C :: *d*. D :: &c.
And alternly *a*. *b*. *c*. &c. :: B. C. D. &c. :: A. B. C. &c.
That is, in continual proportion as A to B, or as $m$ to 1.

14. This being done; the Hyperbolick Spaces $Fl$, $Lm$, $Mn$, &c. are equal. As is demonstrated by *Gregory San-Vincent*; and as such is commonly admitted.

15. So that $Fl$, $Lm$, $Mn$, &c. may fitly represent equal Times, in which are dispatched unequal Lengths, represented by $FL$, $LM$, $MN$, &c.

16. And because they are in Number infinite (though equal to a finite Magnitude) the Duration is infinite: And consequently the impressed Force, and Motion thence arising,

sing, never to be wholly extinguished (without some further Impediment) but perpetually approaching to *A*, in the Nature of Asymptotes.

17. The Spaces *Fl*, *Fm*, *Fn*, &c. are therefore as Logarithms (in Arithmetical Progression increasing) answering to the Lines *AF*, *AL*, *AM*, &c. or to *FL*, *LM*, *MN*, &c. in Geometrical Progression decreasing.

18. Because *FL*, *LM*, *MN*, &c. are as $\frac{1}{m}$, $\frac{1}{mm}$, $\frac{1}{m^3}$, &c. (infinitely) terminated at *A*; therefore (by ¶ 10) their Aggregate *FA* or *dh*, is to *DH*, (so much Length as would have been dispatched, in the same time, by such impressed Force undiminished) as 1 to $m - 1 = n$.

19. If therefore we take, as 1 to *n*, so *AF* to *DH*; this will represent the Length to be dispatched, in the same time, by such undiminished Force.

20. And if such *DH* be supposed to be divided into equal Parts innumerable (and therefore infinitely small;) these answer to those (as many) Parts unequal in *FA*, or *hd*.

21. But, what is the Proportion of *r* to 1, or (which depends on it) of $r - r$ to 1, or 1 to *m*; remains to be inquired by Experiment.

22. If the Progression be not infinitely continued, but end (suppose) at *N*, and its last Term to be $A - MN$; then, out of $\frac{V}{R-1}$ into $\frac{1}{m} + \frac{1}{mm} + \frac{1}{m^3}$, &c. is to be subducted $\frac{A}{R-1}$ (as at ¶ 10) that is (as, by Divi-

sion

sion will appear) $\frac{A}{R} + \frac{A}{R^2} + \frac{A}{R^3}$ &c. That is (in our present Case) $\frac{a}{m} + \frac{a}{m\,m} + \frac{a}{m^3}$ &c. And so the Aggregate will be $\frac{1-a}{m} + \frac{1-a}{m\,m} + \frac{1-a}{m^3}$ &c. $= \frac{1-a}{n}$.

And thus as to the Line of Projection, in which (secluding the Resistance,) the Motion is reputed uniform; dispatching equal Lengths in equal Times. Consider we next the Line of Descent.

23. In the Descent of Heavy Bodies, it is supposed that to each Moment of Time, there is superadded a new Impulse of Gravity to what was before: And each of these, secluding the Consideration of the Air's Resistance, to proceed equally (from their several beginnings) through the succeeding Moments. As (in the erect Lines) 1 1 1 1 &c. 1 1 1 &c. 1 1 &c. 1 &c. and so continually as in the Line of Projection.

1
1 1
1 1 1
1 1 1 1

24. Hence ariseth (in the transverse Lines) for the first Moment 1, for the second 1 + 1, for the third 1 + 1 + 1, and so forth, in Arithmetical Progression: As are the Ordinates in a Triangle, at equal distance.

25. And such are the continual Increments of the Diameter, or of the Ordinates in the exterior Parabola, answering to the interior Ordinates, or Segments of the Tangent, equally increasing; as is known, and commonly admitted.



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26. If we take in the Consideration of the Air's Resistence; we are then for each of these equal Progressions, to substitute a decreasing Progression Geometrical; in like manner (and for the same Reasons) as in the Line of Projection.

27. Hence ariseth, for the first Moment $\frac{1}{m}$; for the second $\frac{1}{m} + \frac{1}{m^2}$; for the third $\frac{1}{m} + \frac{1}{m^2} + \frac{1}{m^3}$ &c. And such is therefore the Descent of a heavy Body falling by its own weight. The several Impulses of Gravity being supposed equal. $\frac{1}{m}$ $\frac{1}{m^2}$ $\frac{1}{m}$ $\frac{1}{m^3}$ $\frac{1}{m^2}$ $\frac{1}{m}$ $\frac{1}{m^4}$ $\frac{1}{m^3}$ $\frac{1}{m^2}$ $\frac{1}{m}$

28. That is (in the Figure of ¶ 12) as $FL$, $FM$, $FN$, &c. in the Line of Descent, answering to $FL$, $LM$, $MN$, &c. in the Line of Projection.

29. But though the Progressions for the Line of Projection, are like to each of those many in the Line of Descent; it is not to be thence inferred, that therefore $\frac{1}{m}$ in the one, is equal to $\frac{1}{m}$ in the other: But in the Line of Projection (suppose) $\frac{1}{m}f$ (such a Part of the Force impressed, and a Celerity answerable:) in the Line of Descent, $\frac{1}{m}g$ such a Part of the Impulse of Gravity.

30. Those for the Line of Descent (of the same Body) are all equal, each to other: Because $g$ (the new Impulse of Gravity) in each Moment is supposed to be the same.

31. But

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31. But what is the Proportion of $f$ to $g$ (that of the Force impressed, to the Impulse of Gravity in each Body) remains to be inquired by Experiment.

32. This Proportion being found as to one known Force; the same is thence known as to any other Force (who's Proportion to this is given) in the same uniform *Medium*.

33. And this being known as to one *Medium*; the same is thence known as to any other *Medium*, the Proportion of whose Resistance to that of this is known.

34. If a heavy Body be projected downward in a perpendicular Line; it descends therefore at the Rate $\frac{1}{m}$, $\frac{1}{mm}$, $\frac{1}{m^3}$, *&c.* of $f$ (the impressed Force, increased by $\frac{1}{m}$, $\frac{1}{m}+\frac{1}{m^2}$, $\frac{1}{m}+\frac{1}{m^2}+\frac{1}{m^3}$ *&c.* of $g$ the Impulse of Gravity, (by ¶ 7. and ¶ 27.) Because both Forces are here united.

35. If in a perpendicular Projection upwards; it ascends in the rate of the former, abated by that of the latter. Because here the Impulse of Gravity is contrary to the Force impressed.

36. When therefore this latter (continually increasing) becomes equal to that former (continually decreasing) it then ceaseth to ascend; and doth thenceforth descend at the rate wherein the latter continually exceeds the former.

37. In an Horizontal, or Oblique Projection: If to a Tangent, whose Increments are as $FL$, $LM$, $MN$, *&c.* that is as $\frac{1}{m}f$, *&c.* be fitted Ordinates (at a given Angle) whose



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Increments are as $FL$, $FM$, $FN$, &c. that is, as $\frac{1}{m}g$, &c. The Curve answering to the Compound of these Motions, is that wherein the Project is to move.

38. This Curve (being hitherto without a Name) may be called *Linea Projectorum*; the Line of Projects, or things projected; which resembles a Parabola deformed.

39. The Celerity and Tendency, as to each Point of this Line, is determined by a Tangent at that Point.

40. And that against which it makes the greatest Stroke or Percussion, is that which (at that Point) is at right Angles to that Tangent.

41. If the Projection (at ¶ 27.) be not infinitely continued, but terminate (suppose) at $N$, so that the last Term in the first Column or Series erect be $a$; and consequently in the second, $ma$; in the third, $mma$, &c. (each Series having one Term fewer than that before it:) then (for the same Reasons as at ¶ 22.) the Aggregates of the several Columns (or erect Series) will be $\frac{1-a}{n}$, $\frac{1-ma}{n}$, $\frac{1-mma}{n}$, and so forth, till (the Multiple of $a$ becoming $= 1$) the Progression expire.

42. Now all the Abatements here, $a$, $ma$, $mma$, &c. are the same with the Terms of the first Column taken backward. For $a$ is the last, $ma$ the next before it; and so of the rest.

43. And

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43. And the Aggregate of all the Numerators is so many times 1, as is the Number of Terms (suppose $t$,) wanting the first Column; that is $t \times \frac{1-a}{n}$, or $\frac{nt-t}{n}$; and this again divided by the common Denominator $n$, becomes $\frac{nt-t}{nn}$. And therefore $\frac{nt-1+a}{nn}$ $g$, is the Line of Descent by its own Gravity.

44. If therefore this be added to a projecting Force downward in a Perpendicular; or subducted from such projecting Force upward; that is, to or from $\frac{1-a}{n} f$: The Descent in the first Case will be $\frac{1-a}{n} f + \frac{nt-1+a}{nn} g$; and the Ascent in the other case $\frac{1-a}{n} f - \frac{nt-1+a}{nn} g$. And in this latter Case, when the ablative Part becomes equal to the positive Part, the Ascent is at the highest; and thenceforth (the ablative Part exceeding the positive) it will descend.

45. In an Horizontal or Oblique Projection, having taken $\frac{1-a}{n} f$ in the Line of Projection, and thence (at the Angle given) $\frac{nt-1+a}{nn} g$ in the Line of Descent; the Point in the Curve answering to these, is the Place of the Projectile answering to that Moment.

46. I am aware of some Objections to be made, whether to some Points of the Process, or to some of the Suppositions. But I saw not well how to wave it, without making the Computation much more perplex'd. And in a Matter so nice, and which must depend upon Physical Observations, 'twill be hard to attain such Accuracy, as not to stand in need of some Allowances.

47 Somewhat might have been farther added to direct the Experiments suggested at ¶ 21, and 31. But that may be done at leisure, after deliberation had, which way to attempt the Experiment.

48. The like is to be said of the different resistance which different Bodies may meet with in the same *Medium*, according to their different Gravities (extensively or intensively considered) and their different Figures and Positions in Motion. Whereof we have hitherto taken no account; but supposed them, as to all these, to be alike and equal.

*Post-script.*

49. The Computation in ¶ 41, 42, 43, may (if that be also desired) be thus represented by Lines and Spaces. The Ablatives *a*, *m a*, *m m a*, *&c.* (being the same with the first Column taken backward) are fitly represented by the Segments of *N F* (beginning at *N*) in Figure 5. and 6. and therefore by Parallelograms on these Bases, assuming the common height of *F h*, or *N Q*; the Aggregate of which is *N h*, or *F Q*. And, so many times 1, by so many equal Spaces, on the same Bases,

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ses, between the same Parallels, terminated at the Hyperbola: The Aggregate of which is *bFNQn*. From whence if we subduct the Aggregate of Ablatives *FQ*; the remaining trilinear *bQn*, represents the Descent.

50. If to this of Gravity, be joined a projecting Force; which is to the Impulse of Gravity as *hK* to *hF* (be it greater, less, or equal) taken in the same Line; the same Parallels determine proportional Parallelograms, whose Aggregate is *KQ*.

51. And therefore if this be a perpendicular Projection downwards; then *bKkn* (the Sum of this with the former) represents the Descent.

42. If it be a Perpendicular upwards; then the difference of these two represents the Motion; which so long as *KQ* is the greater, is Ascendent; but Descendent, when *bQn* becomes greater; and it is then at the highest when they be equal.

53. If the Projection be not in the same Perpendicular, (but Horizontal, or Oblique) then *KQ* represents the Tangent of the Curve; and *bQn* the Ordinates to that Tangent, at the given Angle.

54. But the Computation before given, I take to be of better use than this Representation in Figure. Because in such Mathematical Enquiries, I chuse to separate (as much as may be) what purely concerns Proportions; and consider it abstractly from Lines, or other Matter wherewith it is incumbered.

As

As to the Question proposed; whether the resistance of the *Medium* do not always take off such a proportional part of the Force moving through it, as is the specifick Gravity of the *Medium* to that of the Body moved in it: (for, if so, it will save us the trouble of Observation.)

I think this can by no means be admitted. For there be many other things of Consideration herein, beside the intensive Gravity (or, as some call it, the specifick Gravity) of the *Medium*.

A viscous *Medium* shall more resist, than one more fluid, though of like intensive Gravity.

And a sharp Arrow shall bore his way more easily through the *Medium*, than a blunt-headed Bolt, though of equal Weight, and like intensive Gravity.

And the same Pyramid with the Point, than with the Base forward.

And many other like Varieties, intended in my ¶ 48.

But this I think may be admitted, namely, That different *Mediums*, equally liquid, (and other Circumstances alike,) do in such proportion resist, as is their intensive Gravity. Because there is, in such proportion, a heavier Object to be removed, by the same Force. Which is one of the things to which ¶ 33 refers.

And again: The heavier Project once in Motion, (being equally swift, and all other Circumstances alike) moves through the same *Medium* in such proportion more strongly, as is its intensive Gravity. For now the Force

is

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is in ſuch proportion greater, for the removal of the ſame reſiſtance. And this Part of what my ¶ 32 inſinuates.

But where there is a Complication of theſe Conſiderations one with another, and with many other Circumſtances, whereof each is ſeverally to be conſidered; there muſt be reſpect had to all of them.

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## *An Instance of the Excellence of the* Modern Algebra, *in the Resolution of the Problem of finding the* Foci *of Optick Glasses universally. By* E. Halley, *S. R. S.*

THE Excellence of the *Modern Geometry* is in nothing more evident, than in those full and adequate Solutions it gives to Problems; representing all the possible Cases at one view, and in one general Theorem, many times comprehending whole Sciences; which deduced at length into Propositions, and demonstrated after the manner of the *Ancients*, might well become the Subjects of large Treatises: For whatsoever Theorem solves the most complicated Problem of the kind, does with a due Reduction reach all the subordinate Cases. Of this I now design to give a notable Instance in the Doctrine of *Dioptricks*.

This Dioptrick Problem is that of finding the *Focus* of any sort of *Lens*, exposed either to converging, diverging, or parallel Rays of Light, proceeding from, or tending to a given Point in the *Axis* of the *Lens*, be the *Ratio* of *Refraction* what it will, according to the Nature of the transparent Material whereof the *Lens* is formed, and also with allowance for the thickness of the *Lens* between the *Vertices*

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*tices* of the two Spherical Segments. This Problem being solved in one Case, *mutatis mutandis*, will exhibit Theorems for all the possible Cases, whether the *Lens* be *Double-Convex* or *Double-Concave*, *Plano-Convex*, or *Plano-Concave*, or *Convexo-Concave*, which sort are usually called *Menisci*. But this is only to be understood of those Beams which are neareſt to the *Axis* of the *Lens*, so as to occasion no sensible difference by their Inclination thereto; and the *Focus* here formed, is by *Dioptrick Writers* commonly called the principal *Focus*, being that of use in *Telescopes* and *Microscopes*.

Let then (in *Fig.* 7. *Tab.* 5.) BEβ be a double Convex *Lens*, C the Center of the Segment EB, and K the Center of the Segment Eβ, Bβ the thickness of the *Lens*, D a Point in the *Axis* of the *Lens*; and it is required to find the Point F, at which the Beams proceeding from the Point D, are collected therein, the *Ratio* of Refraction being as *m* to *n*. Let the distance of the Object DB=DA=*d* (the Point A being supposed the same with B, but taken at a distance therefrom, to prevent the coincidence of so many Lines) the *Radius* of the Segment towards the Object CB or CA=*r*, and the *Radius* of the Segment from the Object Kβ or Kε=ϱ; and let Bβ the thickness of the *Lens* be =*t*, and then let the Sine of the Angle of Incidence DAG be to the Sine of the refracted Angle HAG or CAφ as *m* to *n*: And in very small Angles, the Angles themselves will be in the same proportion; whence it will follow that,

As *d* to *r*, so the Angle at C to the Angle at D, and *d*−*r* will be as the Angle of Incidence

dence GAD; and again as $m$ to $n$, so $d+r$ to $\frac{dn+rn}{m}$, which will be as the Angle GAH = GAφ. This being taken from ACD which is as $d$, will leave $\frac{m-nd-nr}{m}$ analogous to the Angle Aφ D; and the Sides being in this Case proportional to the Angles they subtend, it will follow, that as the Angle Aφ D is to the Angle ADφ, so is the Side AD or BD to Aφ or Bφ: That is, Bφ will be $= \frac{mdr}{m-nd-nr}$ which shews in in what Point the Beams proceeding from D, would be collected by means of the first Refraction; but if $nr$ cannot be subtracted from $m-nd$, it follows that the Beams after Refraction do still pass on diverging, and the Point φ is on the same side of the *Lens* beyond D. But if $nr$ be equal to $m-nd$, then they proceed parallel to the *Axis*, and the Point φ is infinitely distant.

The Point φ being found as before, and Bφ − Bβ being given, which we will call $s$, it follows by a Process like the former, that βF, or the focal Distance sought, is equal to $\frac{s\varrho n}{m-ns+m\varrho} = f$. And in the room of $s$ substituting $B\varphi - B\beta = \frac{mdr}{m-nd-nr} - t$, putting $p$ for $\frac{n}{m-n}$ after due Reduction this following Equation will arise,

$$\frac{mpdr\varrho - nd\varrho t + npr\varrho t}{mdt + rmd\varrho - mpr\varrho - m - nd t + nrt} = f.$$

Which

Which Theorem, however it may seem operose, is not so, considering the great Number of *Data* that enter the Question; and that one half of the Terms arise from our taking in the thickness of the *Lens*, which in most Cases can produce no great Effect; however it was necessary to consider it, to make our Rule perfect. If therefore the *Lens* consist of *Glass*, whose Refraction is as 3 to 2 'twill be $\frac{6drq - 2dqt + 4rqt}{3dr + 3dq - 6rq - dt + 2rt} = f$. If of *Water*, whose Refraction is as 4 to 3 the Theorem will stand thus $\frac{12drq - 3dqt + 9rqt}{4dr + 4dq - 12rq - dt + 3rt} = f$. If it could be made of *Diamant*, whose Refraction is as 5 to 2, it would be $\frac{\frac{20}{3}drq - 2dqt + \frac{5}{3}rqt}{5dr + 5dq + \frac{10}{3}rq - 3dt + 2rt} = f$. And this is the universal Rule for the *Foci* of double Convex Glasses exposed to diverging Rays. But if the thickness of the *Lens* be rejected as not sensible, the Rule will be much shorter, *viz.* $\frac{pdrq}{dr + dq - prq} = f$, or in Glass $\frac{2drq}{dr + dq - 2rq} = f$. all the Terms wherein $r$ is found being omitted, as equal to nothing. In this Case, if $d$ be so small, as that $2rq$ exceed $dr + dq$, then will it be $-f$, or the *Focus* will be Negative, which shews that the Beams after both Refractions still proceed diverging.

To bring this to the other Cases, as of converging Beams, or of Concave Glasses, the Rule

Rule is ever composed of the same Terms, only changing the Signs of + and −; for the distance of the Point of Concourse of converging Beams, from the Point B, or the first Surface of the *Lens*, I call a negative distance or $-d$; and the Radius of a Concave *Lens* I call a negative Radius, or $-r$ if it be the first Surface, and $-\rho$, if it be the second Surface. Let then converging Beams fall on a double Convex of Glass, and the Theorem will stand thus $\frac{-2dr\rho}{-dr-d\rho-2r\rho} = +f$, which shews that in this Case the *Focus* is always affirmative.

If the *Lens* were a *Meniscus* of Glass, exposed to diverging Beams, the Rule is $\frac{-2dr\rho}{-dr+d\rho+2r\rho} = f$, which is affirmative when $2r\rho$ is less than $dr-d\rho$, otherwise negative: But in the Case of converging Beams falling on the same *Meniscus*, 'twill be $\frac{+2dr\rho}{+dr-d\rho+2r\rho} = f$. and it will be $+f$, whilst $d\rho-dr$ is less than $2r\rho$; but if it be greater than $2r\rho$, it will always be found negative or $-f$. If the *Lens* be double Concave, the *Focus* of converging Beams is negative, where it was affirmative in the Case of diverging Beams on a double Convex, *viz.* $\frac{-2dr\rho}{+dr+d\rho-2r\rho} = f$, which is affirmative only when $2r\rho$ exceeds $dr+d\rho$: But diverging Beams passing a double Concave, have always a negative *Focus*, *viz.* $\frac{-2dr\rho}{+dr+d\rho+2r\rho} = -f$.

The

The Theorems for converging Beams, are principally of use to determine the *Focus* resulting from any sort of *Lens* placed in a Telescope, between the *Focus* of the Object-glass and the Glass it self; the distance between the said *Focus* of the Object-glass, and the interposed *Lens* being made $= d$.

I here suppose my Reader acquainted with the Rules of Analytical Multiplication and Division, as that $+$ multiplied by $+$ makes the Product $+$, $+$ by $-$ makes $-$, and $-$ by $-$ makes $+$, so dividing $+$ by $+$ makes the Quote $+$, $+$ by $-$ makes $-$, and $-$ by $-$ makes $+$, which will be necessary to be understood in the preceding Examples.

In case the Beams are parallel, as coming from an infinite distance, (which is supposed in the Case of Telescopes) then will $d$ be supposed Infinite, and in the Theorem $\frac{p\,d\,e\,r}{d\,r + d\,e - p\,r\,e}$ the Term $p\,r\,e$ vanishes, as being finite, which is no part of the other infinite Terms; and dividing the remainder by the infinite Part $d$, the Theorem will stand thus $\frac{p\,e\,r}{r + e} = f$, or in Glass, $\frac{2\,r\,e}{r + e} = f$.

In case the *Lens* were *Plano-Convex* exposed to diverging Beams, instead of $\frac{p\,d\,e\,r}{d\,r + d\,e - p\,r\,e}$, $r$ being infinite, it will be $\frac{p\,d\,e}{d - p\,e} = f$, or $\frac{2\,d\,e}{d + 2\,e}$ if the *Lens* be Glass.

If the *Lens* be Double-Convex, and $r$ be equal to $e$, as being formed of Segments of

equal Spheres, then will $\frac{pdqr}{dr+dq-prq}$ be reduced to $\frac{pdr}{2d-pr}f$; and in case $d$ be infinite, then it will yet be farther contracted to $\frac{1}{2}pr$, and $p$ being $= \frac{n}{m-n}$ the focal distance in Glass will be $= r$, in Water $1\frac{1}{2}r$, but in Diamant $\frac{1}{3}r$.

I am sensible that these Examples are too much for the compleat Analyst, though I fear too little for the less Skilful; it being very hard, if possible, in such Matters, so to write as to give satisfaction to both; or to please the one, and instruct the other. But this may suffice to shew the extent of our Theorem, and how ease a Reduction adapts any one case to all the rest.

Nor is this only useful to discover the *Focus* from the other proposed *data*, but from the *Focus* given, we may thereby determine the distance of the Object; or from the *Focus* and Distance given, we may find of what Sphere it is requisite to take another Segment, to make any given Segment of another Sphere cast the Beams from the distance $d$ to the *Focus* $f$. As likewise from the *Lens*, *Focus*, and Distance given, to find the *Ratio* of Refraction, or of $m$ to $n$, requisite to answer those *Data*. All which it is obvious, are fully determined from the Equation we have hitherto used, *viz.* $pdqr = drf + dqf - prqf$, for to find $d$ the Theorem is $\frac{prqf}{rf+qf-pqr} = d$, the distance of the Object.

For

For $e$ the Rule is $\frac{drf}{pdr+df+prf} = e$.

But for $p$ will be $\frac{drf+def}{dfr+fer} = p$, which latter determines the *Ratio* of Refraction, $m$ being to $n$ as $1+p$ to $p$.

I shall not expatiate on these Particulars, but leave them for the Exercise of those that are desirous to be informed in Optical Matters, which I am bold to say are comprehended in these three Rules, as fully as the most Inquisitive can desire them, and in all possible Cases; regard being had to the Signs + and −, as in the former Cases of finding the *Focus*. I shall only shew two considerable Uses of them; the one to find the distance whereat an Object being placed, shall by a given *Lens* be represented in a *Species* as large as the Object it self, which may be of singular Use in drawing Faces, and other things in their true Magnitude, by transmitting the *Species* by a Glass into a dark Room, which will not only give the true Figure and Shades, but even the Colours themselves, almost as vivid as the Life. In this Case $d$ is equal to $f$, and substituting $d$ for $f$ in the Equation, we shall have $pdre = ddr + dde = dper$, and dividing all by $d.pre = dr + de = pre$, that is, $\frac{2pre}{r+e} = d$; but if the two Convexities be of the same Sphere so as $r = e$, then will the distance be $= pr$; that is, if the *Lens* be Glass $= 1r$, so that if an Object be placed at the Diameter of the Sphere distant, in this Case the *Focus* will be as far within as the Object is

without, and the *Species* represented thereby will be as big as the Life; but if it were a *Plano-Convex*, the same distance will be $= 2pr$, or in Glass to four times the *Radius* of the Convexity; but of this Method I may entertain the Curious at some other Time, and shew how to magnifie or diminish an Object in any proportion assign'd, (which yet will be obvious enough from what is here delivered) as likewise how to erect the Object which in this Method is represented inverted.

A second Use is to find what Convexity or Concavity is required, to make a vastly distant Object be represented at a given *Focus*, after the one Surface of the *Lens* is formed; which is but a Corallary of our Theorem for finding $e$, having $p$, $d$, $r$ and $f$ given; for $d$ being infinite, that Rule becomes $\frac{pf}{pr-f} = e$; that is in Glass $\frac{rf}{2r-f} = e$, whence if $f$ be be greater than $2r$, $e$ becomes Negative, and $\frac{2rf}{f-2r}$ is the *Radius* of the Concave sought.

Those that are wholly to begin with this Dioptrical Science, cannot do better than to read with Attention a late Treatise of Dioptricks, published by *W. Molineux*, Esq; R.S.S. who has at large shewn the Nature of Optick Glasses, and the Construction and Use of Microscopes and Telescopes; and though some nicely Critical have endeavoured to spy Faults, and to traduce the Book; yet having long since examin'd it with Care, I affirm, that if I can judge, it hath but two things that with

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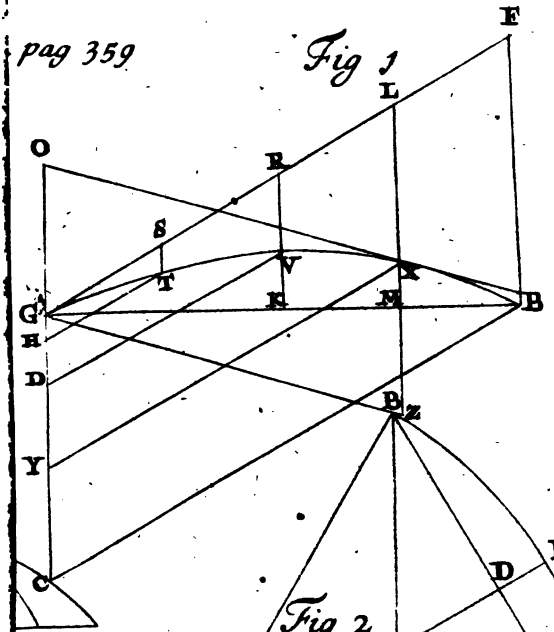
Fig 1



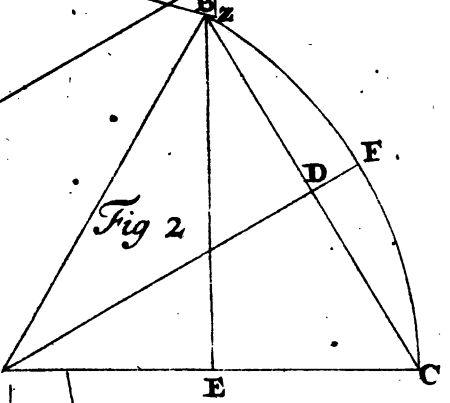




Fig 2

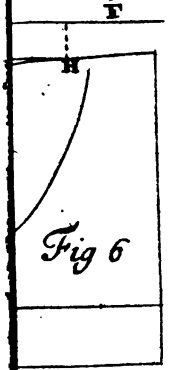



Fig 6

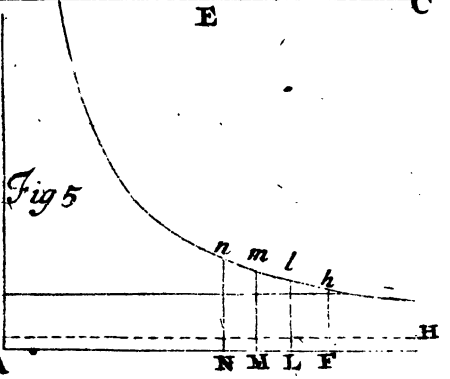



Fig 5

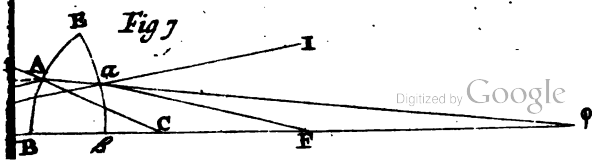



Fig 7

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any Colour may be call'd Faults; the one, an over-careful acknowledgment of every Trifle the Author had receiv'd from others; and the other, that he labours to make easie this curious Subject, so little understood by most, in a manner perhaps too familiar for the *Learned Critick*, and which demonstrates that it was writ *cum animo docendi*, both which require but very little Friendship or good Nature in the Reader, to pass for Vertues in an Author.

But to return to our first Theorem, which accounting for the thickness of the *Lens*, we will here again resume, *viz.*

$$\frac{m\,p\,d\,r\,\varrho - n\,d\,\varrho\,t + n\,p\,r\,\varrho\,t}{m\,d\,r + m\,d\,\varrho - m\,p\,r\,\varrho - m - n\,d\,t + n\,r\,t} = f.$$

And let it be required to find the *Focus* where a whole Sphere will collect the Beams proceeding from an Object at the distance $d$: Here $t$ is equal to $2\,r$ and $r = \varrho$. And after due Reduction, the Theorem will stand thus, $\frac{m\,p\,d\,r - 2\,n\,d\,r + 2\,n\,p\,r\,r}{2\,n\,d + 2\,n\,r - m\,p\,r} = f$; but if $d$ be Infinite, it is contracted to $\frac{m\,p\,r}{2\,n} - r = \frac{2\,n - m}{2\,m - 2\,n}\,r = f$, wherefore a Sphere of Glass collects the Sun-Beams at half the Semi-diameter of the Sphere without it, and a Sphere of Water at a whole Semi-diameter. But if the *Ratio* of Refraction $m$ to $n$ be as 2 to 1, the *Focus* falls on the opposite Surface of the Sphere; but if it be of greater Inequality it falls within.

Ano-

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Another Example shall be when a Hemisphere is exposed to parallel Rays, that is, $d$ and $e$ being infinite, and $t = r$, and after due Reduction the Theorem results $\frac{nn}{mm - mn} r = f$. That is, in Glass it is at $\frac{3}{2} r$, in Water at $\frac{9}{4} r$; but if the Hemisphere were Diamant, it would collect the Beams at $\frac{4}{3}$ of the *Radius* beyond the Center.

*Lastly*, As to the Effect of turning the two sides of a *Lens* towards an Object; it is evident, that if the thickness of the *Lens* be very small, so as that you neglect it, or account $t = 0$; then in all Cases the *Focus* of the same *Lens*, to whatsoever Beams, will be the same, without any difference upon the turning the *Lens*: But if you are so curious as to consider the thickness, (which is seldom worth accounting for) in the Case of parallel Rays falling on a *Plano-Convex* of Glass, if the plain side be towards the Object, $t$ does occasion no difference, but the focal distance $f = 2r$. But when the Convex-side is towards the Object, it is contracted to $2r - \frac{1}{2} t$, so that the *Focus* is nearer by $\frac{1}{2} t$. If the *Lens* be double Convex, the difference is less; if a *Meniscus*, greater. If the Convexity on both sides be equal, the focal length is about $\frac{1}{6} t$ shorter than when $t = 0$. In a *Meniscus* the Concave-side towards the Object increases the focal Length, but the Convex towards the Object diminishes it. A General Rule for the difference arising on turning the *Lens*, where the *Focus* is Affirmative, is this $\frac{2rtt - 2ett}{3rr + 3er - tt}$, for double Convexes of differing Spheres. But for

*Menisci*

*Menisci* the same difference becomes $\frac{2rt+2\varrho t}{3r-3\varrho+t}$; of which I need give no other Demonstration, but that by a due Reduction it will so follow from what is premised, as will the Theorems for all sorts of Problems relating to the *Foci* of Optick Glasses.

# *FINIS.*

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